Contracting nitrogen abatement in the Baltic Proper watershed under the risk of climate change

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Abstract

Within the EU, it is agreed that watershed-based management of water quality problems is likely to be more economically efficient compared to existing institutional arrangements. Watershed authorities, assigned under the European Water Framework Directive, do however lack financial resources for policy implementation. EU funding for agri-environmental measures is mainly channeled through CAP via national governments to the farmers. In this paper, a mechanism for allocating international funds to watershed authorities is investigated assuming that there is a risk of moral hazard on behalf of the regional authority. The assumed purpose of the funding is to reduce nitrogen loads to the Baltic Proper, and the implications of uncertainty about the risk of climate change are investigated. Results shows that the risk premium associated with the presence of moral hazard can be high if there is a high likelihood of climate change and marginal damage is increasing rapidly in loads.

Introduction

Eutrophication of the Baltic Sea is a major environmental problem in the region. The European Marine Strategy Framework Directive should, in principle, guide cooperation between Member States as well as non-EU countries on international water management, such as needed for the Baltic Sea. However, it is feared that the Directive will be weak in this regard, e.g. as the Common Agricultural Policy (CAP) is excluded from reformation with regard to the marine environment (Salomon, 2006). Instead the European Water Framework Directive (WFD), which governs surface and coastal water policies, plays an important role for the development of the ecological status of the sea. Under the WFD, assigned river basin authorities are responsible for water quality. These regional watershed bodies have superior knowledge about landscape and other regional characteristics compared to the central EU-administration or national governments, implying that they can be better suited to identify cost-efficient measures. However, the river basin authorities are delegated the responsibility for water quality management but not equipped with the resources or the power to enforce policies. Instead, EU funds for agri-environmental measures distributed to national governments that, according to guidelines for the Rural Development Programs, develop support schemes for farmers, implying that there is little cost-efficiency across different polluting sectors.

Interaction between centralized and regional governmental bodies, e.g. the EU Commission and the river basin authorities, is characterized by asymmetric information and there is a risk that regional authorities act in their own interest rather than in the interest of the international or national community. This is shown to hinder implementation of nutrient (Eckerberg, 1997) and climate policies (e.g. Collier and Löfstedt, 1997). In the presence of asymmetric information, the use of a principal-agent model is motivated. Most of the literature on asymmetric information in environmental policy analyzes agri-environmental policies assuming adverse selection, implying that the principal cannot judge the farmer's cost of providing environmental quality services (Wu and Babcock, 1995; Moxey, White and Ozanne, 1999; Baerenklau, 2002; Peterson and Boisvert, 2001, 2004), while fewer papers analyze moral hazard where due to uncertainty about the response of ecosystems to farmer activity (e.g. Ozanne at al., 2001; Yano and Blandford, 2008; Ozanne and White, 2008).

In the case of eutrophication, there are difficulties to verify abatement undertaken at the sources due to the large number of emission sources of different kind and the uncertainty about the relationship between abatement at the sources and the corresponding effect on the recipient. Climate change is likely to worsen coastal ecosystems conditions due to e.g. increased release of nutrients from inland sources and increased surface water temperature (Rabalais et al., 2009; Diaz and Rosenberg, 2008; Andersen et al., 2006; Arheimer et al., 2005). The magnitude of effects is dampened if the climate becomes stormier and hence sea water mixing increases (Diaz and Rosenberg, 2008). This impact of climate change can be difficult to detect in the near term, because of the natural weather-driven variability of the systems, and because of these changes also being affected by other economic and human activities (Rabalais et al., 2009).

The purpose of this paper is to analyze a mechanism for allocating international funds for nitrogen abatement to a regional decision-maker, assuming that moral hazard is a problem and that there is a risk of climate change altering the effect of abatement measures. From the international decision-makers point of view, uncertainty about the impact of abatement motives a risk-reducing portfolio of measures. To this end, a state-space formulation of the principal-agent model is used, which builds on Quiggin and Chambers (1998). The novelty of the paper is the application of the model in an empirical context using data for the Baltic Proper watershed. Compared to applied analysis of nutrient policies for the Baltic Sea under the risk of climate change (Gren, 2010), it differs through the inclusion of moral hazard.

Model

In the following a model is developed where it is assumed that there is an international decision-maker, the principal, who wants to distribute allocate resources to the Baltic Proper watershed in the Baltic Sea catchment area in order to have nitrogen loads reduced to the sea. In the watershed, there is a regional decision-maker, an agent, who carries out the abatement. The international and the regional decision-maker recognize that due to the possibility that climate change may affect water- and air-borne nitrogen transports, there is uncertainty about the impact that measures will have on the nitrogen loads to coastal water. Because of the weather-driven variations in loads, they are not able to observe whether climate change has occurred. Therefore, the principal wants to adopt a diversified strategy, that will perform relatively well in both states, given the likelihood of the states. It is also assumed that the international decision-maker is not able to observe the abatement measures actually implemented in each region, but only final loads to coastal waters. This assumption is motivated by the fact that current policies are based on measurement of and targets for coastal loads (HELCOM, 2004, 2007a,b). Notably, there are no official *ex-post* quantifications of measures actually implemented in the sea's drainage area on national or international level (Elofsson and Gren, 2004), confirming the view that international decision-makers are unable to observe measures undertaken. Hence the regional agent can only be compensated based on observed load reductions[1]. Thus the regional agent has an incentive not to reveal the efforts carried out, implying

[1] In reality, to get a reliable estimate of changes in the coastal loads, data for several years have to be collected to account for weather-driven variations.

that moral hazard is a potential problem and that a principal-agent framework is motivated.

The theoretical model presented here builds on the state-space approach suggested by Quiggin and Chambers (1998). It is assumed that the regional agent chooses a vector *x* of nitrogen abatement measures, knowing the associated, state-contingent total reductions of nitrogen loads z_i to coastal waters in different possible states *i.* There are assumed to be two states of nature, one baseline state, *B,* with current nitrogen transports, supposed to be known to both parties from scientific studies, and one state *C,* where climate change has altered nitrogen transports. Transports in each state are assumed to be equally well known to the decision-makers, e.g. based on scientific studies. If an abatement vector *x* is applied and state *B* occurs, then we have a nitrogen load reduction z_B. Alternatively, if *x* is applied and state *C* occurs, then z_C occurs. However, neither the agent nor the principal knows the state at the time when the abatement vector is decided upon. Moral hazard arises because the international decision-maker cannot observe either abatement efforts or the state of nature that really appears. However, the principal knows the abatement technology and the agent's utility function and he has the right to decide on the terms of the contracts with regard to compensation for load reductions achieved. In addition, it is assumed that the principal is risk-neutral and that his preferences depend only upon the net benefits of nitrogen reductions. The agent, on the other hand, is risk-averse, and is free to decide whether to accept or reject the contract offered by the principal.

It assumed that costs for coastal load abatement depend on whether climate change occurs or not because nitrogen cycles are affected by changes in temperature and precipitation. The magnitude of this impact differs between regions and measures, as climate change affects temperature and precipitation differently in different parts of the Baltic Proper watershed and the impact of climate change on nutrient cycles varies across environmental media; air, soils and water.

The regional agent's *ex post* preferences are determined by an additive utility function *w*, with

$$w = u(y) - g(x),$$

where *u* is an increasing and concave function of the payment *y* from the principal and *g* is an increasing and convex function of abatement *x*. Given the assumption about a one-to-one relationship between the abatement vector *x* and the corresponding load reductions z_B and z_C, the effort-cost function can be expressed in terms of a nondecreasing and convex effort-cost function $C(z_B, z_C)$, which states the minimum cost for reaching different combinations of z_i, cf. Quiggin and Chambers (1998). It is here assumed this function is strictly convex, strictly increasing and twice differentiable. The agent's maximum expected utility is then defined by:

$$E(w)=\pi_B u(y_B)+\pi_C u(y_C)-C(z_B,z_C),$$

where $\pi_i > 0$ is the probability of state *i*. The nature of the pollution abatement problem implies that z_B and z_C, are cost complements in the sense that the marginal cost of achieving further reductions in one state is lower if the targeted reduction in the other state is already high (see e.g. Laffont and Martimort, 2002).

The principal's problem is maximize net benefits of abatement through the design of a contract that the agent is willing to sign. In the absence of moral hazard, assuming that the agent's reservation utility is zero, the principal's first best problem is to

$$\underset{y,z}{\text{Max}}\ W^p = \pi_B(bz_B - y_B)+\pi_C(bz_C - y_C) \qquad (1)$$

s.t.

$$\pi_B u(y_B)+\pi_C u(y_C)-C(z_B,z_C)\geq 0, \qquad (2)$$

where *b* is the constant marginal benefit of nitrogen load reductions and (2) is the participation constraint. As abatement is costly, the participation constraint will hold with equality and from the first order conditions for z_B, z_C we get that:

$$u'(y_B)=u'(y_C)=\frac{C'_{zB}}{\pi_B b}=\frac{C'_{zC}}{\pi_C b}, \qquad (3)$$

i.e. the agent gets a complete insurance with equal compensation in both states and efforts are determined by the ratio of marginal costs and expected marginal benefit in each state. However, in the presence of moral hazard and given that the principal cannot observe the state of nature, he must instead solve the second-best problem. In this case, he must define a payment scheme $s(z)$, which guarantees that the principal obtains at least his reservation utility and which is individually rational to the agent in the sense that:

$$(z_B,z_C)\in \arg\max\left\{\pi_B u(s(z_B))+\pi_C u(s(z_C))-C(z_B,z_C)\right\}.$$

This constraint ensures that it is always advantageous for the agent to choose the abatement vector that the international decision-maker wants to implement. The international decision-maker's problem is to design a state-contingent contract structure, where the agent receives y_B if $z=z_B$ and y_C if $z=z_C$ and an arbitrarily large negative payment otherwise. Summing up, the principal's problem is one of choosing *z* and *y* to maximize

$$\underset{y,z}{W^p} = \pi_B(bz_B - y_B)+\pi_C(bz_C - y_C) \qquad (4)$$

s.t.

$$\pi_B u(y_B) + \pi_C u(y_C) - C(z_B, z_C) \geq 0 \tag{5}$$

$$\pi_B u(y_B) + \pi_C u(y_C) - C(z_B, z_C) \geq \pi_B u(y_B) + \pi_C u(y_B) - C(z_B, z_B) = u(y_B) - C(z_B, z_B) \tag{6}$$

$$\pi_B u(y_B) + \pi_C u(y_C) - C(z_B, z_C) \geq \pi_B u(y_C) + \pi_C u(y_C) - C(z_C, z_C) = u(y_C) - C(z_C, z_C) \tag{7}$$

$$\pi_B u(y_B) + \pi_C u(y_C) - C(z_B, z_C) \geq \pi_B u(y_C) + \pi_C u(y_B) - C(z_C, z_B) \tag{8}$$

Equation (5) repeats the agent's voluntary participation constraint and equations (6) — (8) ensure incentive compatibility, i.e. ensure that the agent will always prefer to choose his inputs such that (z_B, z_C) is achieved in the two different states in return for the compensation (y_B, y_C). Given that the concave $u(\cdot)$ and convex $C(\cdot)$ both appear on each side of the IC constraints, one cannot guarantee that the constraints are convex. Although a change in variables could solve this with regard to $u(\cdot)$, see e.g. Laffont and Martimort (2002), a corresponding solution with regard to the two-variable function $C(\cdot)$ is not available. Thus, the Kuhn-Tucker conditions associated with this problem will not guarantee a globally optimal solution but only a locally optimal one. The problem can therefore only be solved numerically using an appropriate solver, which compares the outcome at different local optima.

Empirical data

In the following, the above model is applied to the Baltic Proper catchment, which is the largest basin of the Baltic Sea and severely affected by eutrophication[2]. The watershed includes, partially or wholly, 8 different countries; Finland, Estonia, Latvia, Lithuania, Russia, Poland, Germany, Denmark and Sweden. In this section, calculation of the effort-cost function is first described, followed by a description of the principal's benefits of nutrient reductions and the agent's utility of compensation.

The effort-cost function

In order to calculate the effort-cost function, data on the costs of different measures and on the impact on coastal load in the two states have been collected. The measures included in the calculations are shown in table 1. Data on marginal costs at the sources and on baseline nitrogen transport coefficient for measures in all countries surrounding the Baltic Proper basin have been obtained from Gren et al. (2008). In each country, there are 14 different measures to reduce nitrogen. Eight of those are in the agricultural sector and reduce waterborne loads, three are measures to reduce airborne nitrogen oxide

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[2] I reality, there is no international catchment authority for the Baltic Proper. If the application should fit existing institutions, a Water District Authority under the Water Framework Directive could have been a better choice for the regional agent. The choice of a Baltic Proper catchment authority as the regional agent is determined by available data being disaggregated over measures as well as spatially.

emissions from transport and energy sectors and two are measures directed towards waterborne loads from households and sewage treatment plants. Costs are expressed in 2007 year price level.

Table 1. Abatement measures included in the analysis

Energy sector: Selective catalytic reduction (SCR) on power plants *Transport sector:* SCR on ships SCR on trucks *Wastewater treatment:* Increased cleaning at sewage treatment plants Private sewers	*Agricultural sector:* Reductions in cattle, pigs, and poultry[2] Fertilizer reduction Catch crops Energy forestry Grassland Creation of wetlands Changed spreading time of manure

A measure's impact on the coastal load is assumed to be determined by a constant emission coefficient, different for all measures and regions. Data on this impact for state *B* have been obtained from Gren et al. (2008)[3]. The impact of measures on coastal load under climate change is calculated based on information in the literature. Climate change will alter nitrogen transports in several ways. First, changes in temperature and precipitation will increase nitrogen leaching from arable land (Arheimer et al., 2005; Andersen et al., 2006). Here, the increase in nitrogen leaching is based on the statistically estimated relationship between runoff and leaching presented in Andersen et al. (2006), where it is concluded that a one percent increase in runoff implies a 0.69 percent increase in nitrogen leaching. This is assumed to apply for the whole Baltic Proper region. The expected change in runoff due to climate change is calculated for each country as the averages over two climate change scenarios in Bergström et al. (2001). A higher leaching from arable land is assumed to imply a proportionally higher abatement effect of reductions in fertilizer application, manure management measures and land use measures. If, for example, leaching from fertilizers is l percent in state B and $2l$ percent in state C, then if fertilizer application is reduced by one unit the reduction in leaching will be twice as large in state C. Correspondingly, if catch crop cultivation captures a given percentage of the root zone leaching in the baseline state and the root zone leaching is doubled in state C, then catch crops would capture twice as much nutrients[4].

Nitrogen retention in wetlands depends on the nitrogen load reaching the wetland under consideration (Jansson et al. 1994a; Saunders and Kalff, 2001). Nitrogen retention in wetlands will thus increase under climate change due to the higher leaching from arable land. The additional wetland nitrogen retention in state C is calculated based on the

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[3]The emission coefficient has been obtained through division of the cost at the sources by the marginal cost of reductions in nutrient loads to coastal waters. These data are obtained from the Appendix in Gren (2008).
[4] I.e. the same percentage of the leaching.

increase in nitrogen leaching from arable land and the relative loads from agricultural and point sources, where the latter is obtained from Gren et al. (2008).

Table 2. Percentage change in the effect of nitrogen abatement measures on coastal load in state *C* compared to state *B* for the Baltic Proper basin

	Reduction in fertilizer N	**Manure management reduction of manure N**	**Cultivation of crops which reduce N leaching**	**N retention in wetlands**	**Deposition of airborne emissions**	**Sewage treatment plants/private sewers**
Denmark	7	7	7	3	5	0
Germany	0	0	0	0	5	0
Poland	17	17	17	11	5	0
Sweden	3	3	3	2	5	0
Estonia	14	14	14	11	5	0
Latvia	10	10	10	7	5	0
Lithuania	17	17	17	13	5	0
Russia	14	14	14	4	5	0

Retention of nitrogen in rivers and lakes will be affected by climate change through changes in temperature and precipitation (Jansson et al., 1994b) and changed nutrient leaching from arable land (Arheimer et al., 2005, Saunders and Kalff, 2001). Available studies suggest, however, that the combined river and lake retention, measured as a percentage reduction of nitrogen emitted to inland waters, will remain nearly unaffected by climate change (Arheimer et al., 2005; Andersen et al., 2006). Thus, the relative impact of coastal and inland sources on coastal load reductions does not depend on the state. Also, the impact of measures at sewage treatment and from installation of private sewers is unaffected by climate change.

The influence of climate change on transports of airborne nitrogen is limited (Sanderson et al., 2006). The deposition on the Baltic Sea may be increased by 0 -10 percent (Langner et al., 2005). Here, it is assumed that deposition on the Baltic Proper will increase by 5 percent for all countries, implying that the effect of a given reduction in airborne emissions will be 5 percent larger in state *C*.

The differences in the effect of nitrogen abatement measures between the two states are included in table 2. Data indicate that the impact of abatement measures on coastal loads will be higher if the climate changes, implying that more of the nitrogen load to coastal waters could be abated at the same cost.

In order to calculate the effort-cost function $C\left(z_B, z_C\right)$, the joint minimum cost of simultaneously meeting two randomly chosen nitrogen load targets for each basin, one in each state, is repeatedly calculated with the help of a cost-minimization model including all measures and countries described above. This way, thirty different pairs of nitrogen targets $\left(z_B, z_C\right)$ are assigned to the Baltic Proper basin, together with the corresponding minimum cost of simultaneously meeting these targets. A smooth quadratic cost function is fitted to these observations using the ordinary least-squares methods. The fitted cost function has the following shape:

$$C(z_B, z_C) = \underset{12.56}{0.1527793}\, z_B^2 + \underset{(12.04)}{0.1466592}\, z_C^2 - \underset{(-6.40)}{0.154139}\, z_B z_C ,$$

where nitrogen load reductions are expressed in tons costs in SEK, t-values are included within brackets below the estimated coefficients. The negative sign of the last coefficient confirms that the two targets are cost complements as described above.

The marginal benefit of nitrogen load reductions

The willingness to pay for reduced nitrogen loads to the Baltic Sea have been estimated in a couple of studies (e.g. Frykblom, 1998; Söderqvist, 1996; Söderqvist and Scharin, 2000). However, these estimates may not apply directly to the Baltic Proper sub-basin, as the use of different sub-basins of the sea, e.g. with regard to recreation and housing in the coastal area, varies substantially. Instead, we follow the approach by Mäler (1989), in that the principal's marginal benefit of nitrogen reductions in state *B* is derived from observed policies, assuming that policy-makers equate marginal cost and marginal benefit. Using the model in Elofsson (2010), the marginal costs for nitrogen reductions is estimated to be 16 EUR/kg N for the Baltic Proper if the nitrogen target of the Baltic Sea Action Plan for this basin is met at minimum cost. In the following this is assumed to equal the marginal benefit of reductions in both states.

Regional agent's utility of compensation

The characteristics of the political system favor risk-averse behavior by politicians, although the tendency might be somewhat weaker in federal systems (Rose-Ackerman,1980). Public sector employees have been shown to be more risk-averse compared to private sector employees with regard to their own benefits (Buurman et al., 2009), but it is not obvious that this carry over to decisions made on within their authority as employees. The regional agent is here assumed to be risk-averse with regard to the uncertain compensation they achieve. A simple quadratic utility function, $u(y) = y - \beta y^2$, is used. This choice of utility function implies that the agent's degree of absolute risk aversion at zero compensation, $\left.\frac{-u''}{u'}\right|_{y=0} = 2\beta$. It is assumed that $\beta=0.001$, implying a very low level of risk aversion compared to available estimates of individual risk aversion, see e.g. Saha (1994). However, public risk aversion can be expected to be lower than for individuals due to the larger possibilities to larger actors to diversify risk.

Results

In the following results from the above model are presented, based on calculations with GAMS using the BARON solver. Nitrogen reductions and corresponding compensations under the first best and second best contracts are discussed. The risk premium that the principal would be willing to pay to avoid the moral hazard problem is calculated. The probability of each state is assumed to be common knowledge to the two parties. However, results are calculated for a range of different probabilities of nitrogen transports being altered due to climate change. This is motivated by uncertainty about this probability, where its magnitude is ultimately determined by both uncertain natural processes and uncertain future climate policy (Meinshausen et al., 2009). Finally, the sensitivity of results with regard to assumptions about the marginal benefits of reductions and the degree of risk aversion is investigated.

The first best contract is determined by costs and expected benefits only. Under the first best contract, the smallest expected nitrogen reductions are contracted under equal probabilities. Equal probabilities of the two states can be interpreted as a more risky situation compared to one with unequal probabilities, given that the variance of the two-point distribution is maximized when probabilities are identical. With large differences in probabilities and cost complementarity between reductions in the two states, the marginal cost to increase abatement in the less likely state is low because less abatement is carried out in that state. It is therefore inexpensive to undertake additional nitrogen reductions in the less likely state, which explains the higher expected reductions. Compensation under a first best contract is, essentially, proportional to expected reductions.

Under a second best contract, i.e. when incentive constraints are included, contracted reductions lower and a differentiated compensation scheme is necessary to induce a diversified strategy by the agent. Compensations are determined not only by marginal costs and expected marginal benefit but also by the need to provide the agent with incentives for diversification. The highest compensation per unit of nitrogen reduction, i.e. the highest y_i/z_i, is paid in the most likely state, when the likelihood of the two states is similar. The highest y_i/z_i is paid in the climate change and baseline states, respectively, when the likelihood of the state is 0.6. This is explained by the combination of high marginal costs for increasing abatement in the less likely state and high marginal cost for incentivizing the agent.

In spite of the assumption of the regional agent being little risk averse, the principal's net benefits under second best contracts are clearly below those under first best contracts. Figure 1 below illustrates the risk premium associated with moral hazard, i.e. the difference in net benefits under first and second best contracts. The risk premium is thus the amount that the international decision maker would be willing to pay to have the first best contract instead of the second best. Its size depends on the distribution of probabilities between the states, marginal abatement costs and marginal costs for incentivizing the agent. The latter costs are the highest when the gains from cheating are the largest, and results show that with initial data those gains are the largest when the probability of climate change is 0.7. With this probability, the regional agent makes a large gain from cheating because considerable costs are saved by only providing state *B* reduction in state *C*, while the compensation for providing baseline reductions is still high given that the probability of that state is relatively high. The risk premium also depends on expected marginal net benefit of abatement, which increases if the probabilities become more unequal. This is because the marginal cost of additional abatement in the less likely state falls. Intuitively, abatement in the less likely state becomes more of a costless side-benefit of abatement in the more likely state. This expected marginal benefit of abatement increases more rapidly when the probability of state *C* increases given that it is already larger than 0.5. This is explained by the lower cost for nitrogen reductions in state *C*. The net effect of abatement and incentivization cost is that the largest risk premium is found when the probability of state *C* is 0.8.

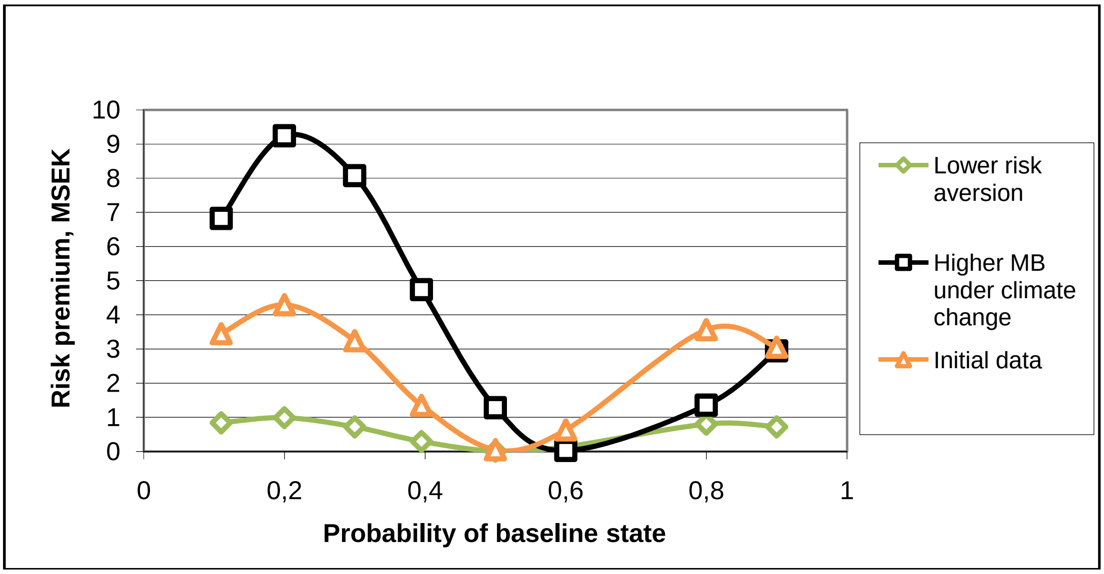

Fig. 1. Sensitivity of risk premium w.r.t. marginal benefit of reductions under change and agent risk aversion.

Sensitivity analysis

In the above calculations, two factors are more uncertain: relative marginal benefits of nitrogen reductions in the two states and risk aversion of the regional agent. A change in the risk aversion only affects the results quantitatively, and therefore the focus here is on the sensitivity of results w.r.t. assumptions about the benefits of load reductions.

Nitrogen loads could be 10-20 percent higher under climate change (Arheimer et al., 2005; Andersen et al., 2006). If the damage function is convex, this would increase the marginal benefit of nutrient reductions. Assuming that climate change implies a 15 percent increase in loads, and noting that the price elasticity of demand for nitrogen reductions is estimated to be approximately -2.0 (Hökby and Söderqvist, 2003), this would imply a 30 percent higher marginal benefit in state *C*. Calculations show that this would increases reductions in both states, if the probability of state *C* is greater than 0.4. Nitrogen reductions are higher in state *C* also when the probability of that state is low, but at the expense of lower reductions in state *B*, as resources are reallocated to provide higher reductions in the less likely state *C* while reductions in state *B* are expensive. The higher marginal benefit in state *C* increases compensation in both states because of higher abatement costs for all probabilities and higher marginal costs for incentivizing the agent when the likelihood of state *C* is high. In figure 1, the sensitivity of the risk premium with regard to above changes in parameters is illustrated. With an assumed higher marginal benefit of abatement under climate change, the risk premium is increases considerably when the likelihood of state *C* is high, reaching a maximum when the probability of state *C* is 0.8, but it is reduced when likelihood is low. The latter is explained by the marginal cost for incentivizing the agent being smaller as the cost-saving from only providing state *C* reductions in state *B* are smaller when contracted reductions are more similar. To investigate the role of assumptions about agent's risk aversion, the effect of assuming that $\beta=0.0001$ is investigated. Results show that the risk premium is generally lower under a lower agent risk aversion compared to the outcome with initial assumptions.

Discussion

Delegation of funds for nitrogen abatement to lower level governmental bodies is associated with several difficulties. Resources should, ideally be allocated such that the maximum net benefits are achieved. This requires information on costs and benefits of abatement in different regions as well as tools to evaluate the role of uncertainty about the response of ecosystems to abatement. Earlier research has shown that there is a risk of moral hazard on behalf of lower level governments, implying that it can be necessary to provide the lower level government with incentives to act in the interest of the larger society. In this paper, a scheme is developed which takes moral hazard into account when the target is to reduce nitrogen loads to the Baltic Proper, acknowledging that there is uncertainty about whether climate change will alter nitrogen transports. The paper shows that if lower level governments act in their own interest in the presence of uncertainty of the effect of abatement, compensation schemes need to be adjusted to take this into account. Even when such adjustment is made, the presence of moral hazard reduces the overall benefits to society from policies to lower nitrogen loads to the Baltic Proper. The loss depends on the likelihood of climate change, the difference in the benefits of nitrogen reductions under climate change compared to current conditions and the degree of risk aversion by the regional government. Relating the above scheme to the existing institutions for water management, this loss should be compared with the gains of delegating abatement decisions to the regional level instead of distributing funds within the CAP framework, noting that these gains are determined by the potentially higher skill of the regional governments in indentifying low-cost abatement strategies.

It should be recognized that some of the input data used for the calculations in this paper are uncertain. First, it is assumed that the likelihood of climate change affecting nitrogen transports is known to both parties. The real-world uncertainty about this likelihood is here addressed through analyzing the consequences of different assumptions about this likelihood, while maintaining the assumption that the likelihood is given and perceived equal by the two parties. One way to develop the model in the future would therefore be to allow for an uncertain probability of climate change affecting nitrogen transports and for differences in risk perception (cf. e.g. Sjöberg, 2000)

Second, it is assumed that actual load reductions to the coast can be confirmed. However, it may take a long time before it is possible to adequately judge the average load, given the natural fluctuations. This would require either regional governments to be patient in waiting for the compensation or preliminary compensations being paid based on limited evidence. Yet, one should note that this problem is already present in the existing international policy, where international agreements are expressed and countries performance is evaluated in terms of coastal loads. The compensation scheme analyzed above is hence based on similar premises as the existing policy.

Third, the results build on the assumption that the degree of risk aversion by the regional agent is known. That is hardly the case in reality. Currently, there is limited knowledge on the attitude of governments towards risky environmental projects. It is sometimes suggested that the degree of risk aversion is reflected in the income distribution (Carlsson et al., 2005), but other studies show that it might be not the risk aversion itself which varies across countries but rather the perception of risk (Weber and Hsee, 1998) and the political system (Rose-Ackerman, 1980).

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