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Abstract

Many fish stocks have been exhausted or are currently overexploited. Cooperative management of common fish pools may be necessary to sustain stock levels and future harvests. Even when countries have differing time preferences, and thus conflicting management objectives, it has been proven that cooperation can be set up such that it benefits every country involved. This, however, may require higher shares of the harvest for countries with lower discounting factors. A game theoretical approach is used to show that hiding time preferences may be a beneficial strategy for individual players. This is shown, however, to be detrimental for total welfare. The bioeconomic model proposed by Levhari & Mirman (1980), and extended by Breton & Keoula (2014), is used as a frame and optimal management strategies are determined. When cooperating, players are given a weight. These weights are then used to establish harvesting levels, by maximizing the sum of each players weighted utility. Three methods for establishing weights are proposed. This is done in order to capture real life situations. Reporting a lower discount factor is proven to be beneficial under several scenarios depending on actual time preferences, growth potential of the stock considered and how weights are set. A second-best policy is then set up so that a truthful player (the Principal) may induce the other player (the Agent) to report truthfully as well. This comes at a cost for the Principal in terms of information rent. The second-best arrangement is however often preferred over the outcomes associated with i) competition or ii) cooperation with a misreporting Agent. Finally, the case where both players are misreporting is examined. It is shown that both players may have incentives to report lower discount factors. This may potentially lead to a standard “prisoners’ dilemma” situation, where the parties involved would be better off if reporting truthfully.

Contents

Problem statement

The management of common fish pools is a problematic issue. Without cooperation, the profit maximizing behavior of involved parties may lead to an overexploitation of the resource, and in the worst case to stock exhaustion. The overuse of the resource may limit future consumption and may reduce future social welfare. Historically, several common fish pools have been exhausted all around the world.[1] Currently many fish species are under the threat of extinction.

A policy measure to deter exhaustion, which has been both widely studied and used, is the introduction of fishing quotas, fixing the total catches for each participating party. Once agreed upon a set of quotas, harvest can be held at a sustainable level, allowing the fish stocks to naturally replenish. Future harvests can then be sustained at higher levels than in the case of competition between countries.

The main research questions in this thesis are the following: i) under what circumstances do countries have incentives to hide their time preferences when bargaining over fishing quotas? and ii) how does this affect fish stocks and harvest?

In order not to exhaust natural resources and allow for future consumption, an understanding of the policy of fishing quotas is important. Studying potential strategies and behaviors by participating countries increase understanding of observed historical patterns. For policy makers, this may facilitate cooperation, which is potentially welfare improving.

Objectives

The purpose of this thesis is to contribute to a better understanding of the management of common fishing pools. This is done at the presence of information asymmetry and having in mind the sustainable use of these natural resources as ultimate goal.

This thesis will determine whether hiding time preferences in bargaining over fishing quotas can be strategically beneficial at an individual country level.

What will be established is:

[1] A primary example is the cod population that was exhausted in Newfoundland 1992 (Finlaysson, 1994), and other examples are plentiful (Cochrane, 2000).

- What happens under competition and cooperation when both countries report their actual time preferences?
- What happens when one country optimizes its individual utility by choosing which discount factor to report to the other country?
- Can one country prevent the other from misreporting their time preferences, by designing a second-best policy?
- What are the optimal strategies if both countries have the option to misreport their time preferences?

Literature review

Studies in the management of common fish pools began in the late 1970's and early 1980's (Bailey, Sumalia & Lindroos, 2010). Among the first studies, we find the seminal work by Levhari and Mirman (1980). The authors use a game theoretical approach to shed light on the economic implications of competition in the management of common fish pools. Levhari and Mirman (1980) establish that conflicts over fishing rights lead to non-optimal management of common fish pools, where competition between countries leads to a lower steady state of the population and hampers future harvest as well as social welfare. Using a Cournot-Nash equilibrium framework, the authors derive how much each country in a duopoly harvest in a dynamic bioeconomic model. Stock level depends on the stock level of the previous period, its natural growth rate and both countries' harvest. Levhari and Mirman (1980) assume that the behavior of each country depends on current fish stock and expected harvest of the other country. Taking this and the other country's harvest into account, the authors create reaction functions for both countries. Equilibrium levels of harvests and stock level relative to its saturation are established as functions of discount factors and the growth of the population. The case of competition is then compared to levels of stock and harvests when the countries cooperate and act as a monopoly. It is shown that harvest relative to the stock level is higher in the case of competition. The steady state of the stock is lower and so is the steady state harvest.

The model proposed by Levhari and Mirman (1980) has since the 1980's been widely used and extended upon. The bioeconomic model, with a natural growth rate of the resource, has been proven to give a realistic presentation of the growth of stocks of different fish species (Bailey, Sumalia & Lindroos, 2010). Game theoretical approaches have been applied to investigate competition, cooperation and harvesting behavior within the management of common fish pools. Coalitions of more than two countries have been studied, increasing the difficulties of cooperation, resulting in competition and welfare losses (Bailey, Sumalia & Lindroos, 2010). Cheating the agreements by overfishing has been proven to be economically beneficial, and potential for cooperating after cheating is detected is minimal (Björndal & Lindroos, 2014). Cheating has also been shown leading to more cheating being the optimal response by the other players (Hannesson, 2007).

An extension of the model by Levhari and Mirman (1980), central to this thesis, is the allowance of players with heterogeneous time preferences. Cooperative management of common fish pools, when players have different discount factors was studied by Breton and Keoula (2014). In their extension of the model, possible coalitions are established by giving countries different strategical weights. The total weighted utility is then maximized by establishing how much each country harvest. It is shown that cooperation between countries with heterogeneous time preferences is still possible if higher weights are given to more impatient players using lower discount factors. Maximizing the sum of weighted utility has been used in various studies to establish harvesting levels of each country. Different methods of establishing these weights have been used. For instance, Houba et al. (2000) use a bargaining procedure with one country proposing weights and Rettieva (2014) uses the Nash bargaining procedure (Nash, 1950). In the Nash bargaining, the product of weighted individual gains of cooperation is maximized.

The cooperative outcomes and general setup of the model studied by Levhari and Mirman (1980) will serve as the baseline for this study, where most assumptions and model specifications are the same. For instance, the results from the competition will be the outcome in this model if collusion is not attained. The result found by Breton and Keoula (2014), that higher weights are needed for more impatient players, is central in this thesis. The result leads to the interesting conclusion that hiding discount factors can increase bargaining power when choosing harvest levels and can potentially serve as a strategy that can increase the utility of single players. This choice of misreporting time preferences is mainly what will be further analyzed in this study. As references as to how the bargaining procedure may function, the papers written by Houba et al. (2000) and Rettieva (2014) will be used.

Conceptual framework

In order to investigate whether hiding time preferences may be strategically beneficial, a model will be constructed where one player optimizes his utility by choosing which discounting factor to reveal to the other player. To find what happens in equilibrium in this stage of the game, we need to know what happens in the second stage, where bargaining takes place. This is when the two players bargain over strategical weights that in turn will determine harvest levels of each player. If bargaining fails, harvesting will be established by competition between the players. It is then necessary to know what happens in competition to find what players gain from cooperation and to find the equilibrium of the bargaining stage of the game. In cooperation, the sum of weighted utility of both players will be maximized by choosing corresponding levels of harvest, using revealed discount rates. It will first be presented what happens in competition. We will then have a look at what happens in cooperation with chosen weights, and finally what happens when these strategical weights are manipulated by choosing to reveal another discount factor.

In the model, following Levhari and Mirman (1980), an exponential function of the natural growth of the population is used. Stock levels are normalized such as the saturation level is equal to 1 and the stock of any given period is denoted by S_t, where:

$$0 \leq S_t \leq 1$$

The natural growth of the stock follows:

$$S_{t+1} = {S_t}^{\alpha} \qquad (1)$$

α is between 0 and 1, depending on the regeneration rate of the population in question. If α is 1, the resource is non-renewable, and for lower values of α, the regeneration rate is higher. Harvest in period t is denoted by x_{it}, while total harvest is $X_t = \sum_{i=1}^{2} x_{it}$, where *i* denotes players, *i* ϵ (1,2). Harvest is restricted by the current stock such that:

$$0 \leq X_t \leq S_t \leq 1$$

The evolution of the stock level thus follows:

$$S_{t+1} = (S_t - X_t)^{\alpha} \qquad (1.1)$$

and $S_t - X_t$ is the residual stock. The time specific utility of each player u_{it} is assumed to be a logarithmic function of harvest:

$$u_{it} = log x_{it} \qquad (2)$$

Note that as the utility function is logarithmic and x_{it} takes values between 0 and 1, the utility associated with the harvest will always be negative. With no loss in terms of interpretation, a lower absolute value of the utility is preferred. Players discount future utility with their respective discount factors, δ_i.

Levhari and Mirman (1980) show that, in a setting of two players, both would be better of coordinating catches, together acting as a monopoly. This analysis was conducted using homogenous discount rates. With heterogeneous discount rates, the players could still theoretically coordinate their catches such that combined utility is maximized. This would however lead to catches from the more impatient player tending to zero. As stated in Houba et al. (2000) such a maximizing scheme is unlikely and politically unfeasible. Instead, Houba et al. (2000) propose a bargaining procedure in which catches in cooperation are determined and in Rettieva (2014) weights are established maximizing the factor of weighted individual utility gains from cooperation.

Breton and Keoula (2014) find that whatever discount factors, cooperation can always be profitable by choosing appropriate strategical weights. In their model, catches are determined by maximizing the total weighted utility of the players involved. The objective function is then:

$$Max_x \left\{ \sum_{i=1}^{M} \gamma_i V_i^C \right\} \tag{3}$$

where M is the number of players, γ_i is the weight for player *i* and V_i^c is the value function for player *i* under cooperation. This value function is the sum of the value from current harvest and discounted future harvests. Results from Breton and Keoula (2014) show that this value function is:

$$V_i^C(\gamma, \delta) = A_i^C(\gamma, \delta) + (1 + \beta_i) \log s, \text{where} \tag{4}$$

$$A_i^C(\gamma, \delta) = (1 - \delta_i)^{-1}(log\, h_i^C + \beta_i \log q^C),$$

and

$$\beta_i = \frac{\alpha\delta_i}{1 - \alpha\delta_i}$$

$$h_i^C = \frac{\gamma_i}{G}\frac{1}{B + 1}$$

$$q^C = \frac{B}{B + 1}$$

$$B = \frac{\sum_{i=1}^{M} \gamma_i \beta_i}{G}$$

$$G = \sum_{i=1}^{M} \gamma_i$$

The portion of the stock harvested by each player is h_i^C while q^C is the portion that is not harvested. The harvest levels and corresponding value functions are compared to those emerging from competition. The competitive outcomes are as follows:

$$V_i^N(\delta) = A_i^N(\delta) + (1+\beta_i)\log s, \qquad (5)$$

where

$$A_i^N(\delta) = (1-\delta_i)^{-1}(log\, h_i^N + \beta_i \log q^N),$$

and

$$h_i^N = \frac{1}{\beta_i(b+1)}$$

$$q^N = \frac{1}{b+1}$$

$$b = \sum_{i=1}^{M} {\beta_i}^{-1}$$

When discount factors differ, a higher weight should be given to more impatient parties in order to have all parties involved benefiting from cooperation.

The conjecture of this thesis is that misreporting time preferences will be economically beneficial for more patient players. Since the more patient player has got more to gain from establishing cooperation, an impatient player will have more bargaining power. The impatient player will then be able to secure a higher share of the total harvest. Reporting a lower discount factor should then result in a higher share of the total harvest. However, hiding time preferences, in the case with a patient player reporting a lower discount factor, would also result in a higher level of harvest given a certain level of population. This means that, a lower discount factors result in lower levels of steady state population and lower steady state harvests. This also reduces the utility of the patient player and thus dampens or potentially completely counteracts the benefits from hiding actual time preferences.

Methods and procedure

The methods used in this thesis consist of a game theoretic approach and economic modelling with mathematical maximization and minimization. The model is based on a game consisting of three stages. The game is solved using backwards induction. The last stage is simply cooperation or competition between countries, as established by Levhari and Mirman (1980) and Breton and Keoula

(2014). In the second stage, the bargaining stage, weights are decided and attributed to countries. These weights then determine the outcomes in the last stage. If no agreement can be reached, catches will be determined by the competition between the countries. The first stage presents the novel element by which this research contributes to the literature investigating “the great fish war” model. In this stage, countries report the time preferences that are going to be used for establishing the weights.

The objective function to be maximized by the misreporting player is the gains from misreporting, π^m. Compared to the case when the report is truthful, misreporting alters weights and harvesting levels. The actual utility when misreporting, however, is derived using the actual discount factor. This value, subtracted by the utility derived from a truthful report, is the gains from misreporting. Meanwhile, the believed value functions from cooperation should always be kept at least as high as the believed outcomes of competition for both players, in order to have cooperation preferred.

$$\pi^m = V_1^C(\gamma^m, \delta_1) - V_1^C(\gamma, \delta_1) \tag{6}$$

$$V_i^C(\gamma^m, \delta_i^m) > V_i^N(\gamma^m, \delta_i^m) \tag{7}$$

δ_i^m denotes the misreported discount factor and γ^m is the vector of corresponding weights decided with the misreported discount factors. Equation 7 enables the misreporting player to obtain a higher strategical weight, by having the other player believe that the first would be better of competing, if weights are not altered.

This research will establish whether or not misreporting time preferences is beneficial, and if so, to establish if there exist an optimal level of the misreported discount factor. This will likely depend on the growth rate, as well as the time preferences of the players. The results will also depend on how weights are attributed to the players in the bargaining stage of the game. Analysis will be carried out for three different procedures, These are i) one player proposing weights, ii) the Nash bargaining and iii) a third party already having decided how the weights are set.

The method used will give key insights to the purely economic incentives of misreporting time preferences in the joint management of a common fish pool. Given some assumptions, it will be shown if utility can be improved by not revealing ones actual time preferences. The model is built with two players, but could easily be extended to involve several players and can be adapted for real life scenarios. The model is built upon a strong foundation of previous research and modeling. The extension examined in this thesis should then be analytically tractable. The overfishing and overuse of other natural resources call for a change in how resources are managed. Misreporting time preferences in the joint management of fish pools may be both an economically dominant strategy and welfare harming. This makes the study socially relevant. As discussed further in the conclusion, the problem of misreporting can also be applied to the management of other resources or other international issues. As the model is a simplification of the reality, some aspects of the cooperation are not taken into account. The moral unwillingness of countries to misreport time preferences is one such aspect. Misreporting may be economically beneficial, but moral or ethical reasons may still have players reporting true preferences. Capturing this aspect could be done using a method based on interviews with people involved in decision making for harvests and fishing quotas. This would however not lead to any quantitative results as shown in this thesis. For this reason, economic modelling is used in this thesis. How non-rational behavior affects harvest and stock levels is left as an interesting question open for future research.

People may very well find moral or ethical values in honesty. One may ask if it is unethical to study reporting choices or claim that misreporting is an unethical behavior. In this thesis, however, only the purely economic aspect of misreporting is discussed. In real life, honest behavior may still occur even if there are economic incentives to misreport preferences. One potential shortcoming of the model in this thesis is that it is purely theoretical. It can thus be difficult to apply to real life scenarios. Best possible attempts are however made to make the model more easily applied. How the bargaining procedure transpires can be adjusted and in order to account for non-identical countries (except for the discount factor), changes in the utility functions could be made. Further discussion of applications to real life scenarios can be found in the conclusions.

Misreporting time preferences

So far, outcomes from cooperation and competition have been presented in the case where both players are reporting their true time preferences. These outcomes were the results of the work by Levhari and Mirman (1980) and Breton and Keoula (2014). The first contribution of this thesis to the model is the potential for player 1 to misreport time preferences. As the reporting stage of the game is introduced, the value function for player 1, when misreporting, becomes the following:

$$V_1^C(\gamma^m, \delta) = A_1^C(\gamma^m, \delta) + (1 + \beta_1) \log s, \tag{8}$$

where

$$A_1^C(\gamma^m, \delta) = (1 - \delta)^{-1}(log\, h_1^{Cm} + \beta_1 \log q^{Cm}),$$

and

$$\beta_i{}^m = \frac{\alpha\delta_i{}^m}{1-\alpha\delta_i{}^m}$$

$$h_i^{Cm} = \frac{\gamma_i{}^m}{G^m}\frac{1}{B^m+1}$$

$$q^{Cm} = \frac{B^m}{B^m+1}$$

$$B^m = \frac{\sum_{i=1}^{M}\gamma_i{}^m\beta_i{}^m}{G^m}$$

$$G^m = \sum_{i=1}^{M}\gamma_i{}^m$$

However, if player 1 is misreporting his time preferences, this value function is not public knowledge. The other player will instead believe that the value function of the first player is as follows:

$$V_1^C(\gamma^m,\delta^m) = A_1^C(\gamma^m,\delta^m) + (1+\beta_1{}^m)\log s, \qquad (9)$$

where

$$A_1^C(\gamma^m,\delta^m) = (1-\delta^m)^{-1}(log\, h_1^{Cm} + \beta_1{}^m\, log\, q^{Cm})$$

This may result in a higher weight in the cooperation for the first player, since player 2 otherwise would believe that player 1 would not gain from cooperating. This is creating an incentive for player 1 to misreport time preferences.

If no cooperation were to be established, the revealed competitive outcomes would be as follows:

$$V_i^N(\delta^m) = A_i^N(\delta^m) + (1+\beta_i{}^m)\log s, \qquad (10)$$

where

$$A_i^N(\delta^m) = (1-\delta_i{}^m)^{-1}(log\, h_i^{Nm} + \beta_i{}^m \log q^{Nm}),$$

and

$$h_i^{Nm} = \frac{1}{\beta_i{}^m(b^m+1)}$$

$$q^{Nm} = \frac{1}{b^m + 1}$$

$$b^m = \sum_{i=1}^{M} \beta_i^{\ m-1}$$

The cooperative outcomes are always Pareto-efficient compared to outcomes of competition, as proved by Breton and Keoula (2014). Hence, competitive outcomes never materialize. They will however, serve as threat points for which weights have to be established in such a way that the competitive outcomes are never preferred over the cooperative outcomes.

The gain from misreporting is the value of the cooperating outcome when misreporting, subtracted by the cooperating outcome when the report is truthful. The gains from misreporting are:

$$\pi^m = V_1^C(\gamma^m) - V_i^C(\gamma) \tag{11}$$

$$= A_1^C(\gamma^m) + (1+\beta_1)\,log(s) - \left(A_1^C(\gamma) + (1+\beta_1)\,log(s)\right)$$

$$= A_1^C(\delta, \gamma^m) - A_1^C(\delta, \gamma)$$

$$= (1-\delta)^{-1}\left(log\, h_1^{Cm} + \beta_1 \log q^{Cm} - \left(log\, h_1^C + \beta_i \log q^C\right)\right) \tag{11.1}$$

The optimal report is at the point where the derivative of the gains with respect to $\beta_1{}^m$ (or $\delta_i{}^m$) is zero. The second derivative should be negative. This is not proven but will be visible in figures shown in the next section. The misreported discount factor only affects h_i^{Cm} and q^{Cm}. How these variables are affected depends on how the weights are affected by the misreporting.

When looking at the incentives for misreporting, we will see three different scenarios for how the weights are established and how the weights are affected by the reported discount factor. First, we will see what the optimal reporting is if the weights are exogenous and could for example be set by a third party. The report has then no effect on the deciding of weights. This could be the case of an authority already having decided how the cooperation is to be managed. In the second case, player 2 is free to propose weights according to the reported discount factors. Player 1 can then only accept or reject the offer. If rejected, competitive outcomes would materialize. The weights are thus endogenous and are affected by the reported discount factors. A real world example where such a setup could exist would be when a collusion of countries, acting as one player, is considering including an additional country to the collusion, and proposes to this country how the quotas would be set. This method of deciding the weights will later be used for a second-best policy designed by one of the players, in order to keep the other truthful. In the last case, the two players bargain over the weights using the Nash Bargaining Procedure (Nash, 1950). In this case as well, the weights are endogenous and affected by the misreported discount factor. Out of the three, this procedure is likely to be the most realistic when two players are considering the joint management instead of competition. When allowing for misreports by both players, the Nash bargaining will be used to establish weights. This choice is to keep both players having the same bargaining power.

It is important to highlight the difference between weights and quotas. The weights indicate which player is prioritized when the collision is maximizing the combined utility of participating countries. The quotas, or simply the harvest levels, result from the established weights, but are also affected by the discount factors.

Exogenous weights

When misreporting does not affect weights, the derivative of the gains from misreporting with respect to ${\beta_i}^m$ is:

$$\frac{\delta\pi^m}{\delta{\beta_1}^m} = (1-\delta)^{-1}\left(\frac{\beta_1\gamma_1(\gamma_1+1)}{(\gamma_1{\beta_1}^m+\beta_2)(\gamma_1{\beta_1}^m+\gamma_1+\beta_2+1)} - \frac{\gamma_1}{(\gamma_1{\beta_1}^m+\gamma_1+\beta_2+1)}\right) \quad (12)$$

Here, $\gamma_2$is normalized to 1, such that the interpretation of γ_1 is the relative weight for player 1, compared to the weight of player 2. The 2nd derivative is negative and can be found in appendix 1. The derivative with respect to ${\beta_i}^m$ is used, for the sake of simplicity but at no loss in terms of interpretation, as a proxy for the discount factor and is also in line with the works of Breton and Keoula (2014). As ${\delta_i}^m$ increases, so does ${\beta_i}^m$.

Proposition 1. - *When the weights are exogenously given, the optimally reported ${\beta_1}^m$ is:*

$${\beta_1}^m = \beta_1 + \frac{\beta_1-\beta_2}{\gamma_1} \quad (13)$$

- Or, if rearranged in terms of discount factors:

$${\delta_1}^m = \delta_1 + \frac{\delta_1-\delta_2}{\gamma_1} \quad (13.1)$$

Proof: Maximizing the gains of misreporting (equation 12) gives:

$$\frac{\beta_1\gamma_1(\gamma_1+1)}{(\gamma_1{\beta_1}^m+\beta_2)(\gamma_1{\beta_1}^m+\gamma_1+\beta_2+1)}=\frac{\gamma_1}{(\gamma_1{\beta_1}^m+\gamma_1+\beta_2+1)} \qquad (14)$$

$$\beta_1\gamma_1(\gamma_1+1)=\gamma_1(\gamma_1{\beta_1}^m+\beta_2)$$

$$\beta_1\gamma_1+\beta_1=\gamma_1{\beta_1}^m+\beta_2$$

$${\beta_1}^m=\beta_1+\frac{\beta_1-\beta_2}{\gamma_1}$$

Expressing the result in terms of discount factors instead of ${\beta_1}^m$, this is:

$$\frac{\alpha{\delta_1}^m}{1-\alpha{\delta_1}^m}=\frac{\alpha\delta_1}{1-\alpha\delta_1}+\frac{\frac{\alpha\delta_1}{1-\alpha\delta_1}-\frac{\alpha\delta_2}{1-\alpha\delta_2}}{\gamma_1} \qquad (15)$$

$$\alpha\frac{{\delta_1}^m}{1-\alpha{\delta_1}^m}=\alpha\left(\frac{\delta_1}{1-\alpha\delta_1}+\frac{\frac{\delta_1}{1-\alpha\delta_1}-\frac{\delta_2}{1-\alpha\delta_2}}{\gamma_1}\right)$$

$$\frac{1-\alpha{\delta_1}^m}{{\delta_1}^m}=\frac{1-\alpha\delta_1}{\delta_1}+\frac{\gamma_1(1-\alpha\delta_1)}{\delta_1}-\frac{\gamma_1(1-\alpha\delta_2)}{\delta_2}$$

$$\frac{1}{{\delta_1}^m}-\alpha=\frac{1}{\delta_1}-\alpha+\frac{\gamma_1}{\delta_1}-\gamma_1\alpha-\frac{\gamma_1}{\delta_2}+\gamma_1\alpha$$

$${\delta_1}^m=\delta_1+\frac{\delta_1-\delta_2}{\gamma_1}$$

The result is thus not dependent on the level of growth in the resource when the weights are exogenously given. When δ_1 is equal to δ_2, the optimal level of reported ${\delta_1}^m$ is equal to the actual value. When $\delta_1 > \delta_2$, the optimal reported ${\delta_1}^m$ is higher than the actual δ_1, and when $\delta_2 > \delta_1$, the optimal ${\delta_1}^m$ is lower than the actual δ_1. In other words, δ_2 has a negative effect on the optimally reported ${\delta_1}^m$. The higher is δ_2, the lower will be the optimal ${\delta_1}^m$.

In addition, in order for this solution to be optimal, it not only has to maximize the gains for player 1 from misreporting, but also has to keep player 2 believing to be at least not worse off than under competition. This is:

$$V_2^C(\gamma, \delta^m) \geq V_2^N(\delta^m) \tag{16}$$

Player 2 proposing weights

When allowing player 2 to set the weights according to reported preferences, weights will be set such that cooperating and competing result in what player 2 believes to give equal values for player 1. This is when:

$$V_1^C(\gamma^m, \delta^m) = V_1^N(\delta_i^m) \tag{17}$$

The derivation of the optimally proposed weight is shown in appendix 2. This is:

$$\gamma_1{}^m = \left(q^{Nm} + \frac{q^{Nm}(\gamma_1{}^m + 1)}{(\gamma_1{}^m \beta_1{}^m + \beta_2)}\right)^{\beta_1{}^m} h_1^{Nm}(\gamma_1{}^m \beta_1{}^m + \beta_2 + \gamma_1{}^m + 1) \tag{18}$$

When the weights change as the discount factors and β change, the derivative of the gains from misreporting with respect to β_1 also change. This is now:

$$\frac{\delta \pi^m}{\delta \beta_1{}^m} = (1-\delta)^{-1}\left[\left(\frac{\delta \log h_1^{Cm}}{\delta \beta_1{}^m} + \frac{\delta \log h_1^{Cm}}{\delta \gamma^m}\frac{\delta \gamma^m}{\delta \beta_1{}^m}\right) + \beta_1\left(\frac{\delta \log q^{Cm}}{\delta \beta_1{}^m} + \frac{\delta \log q^{Cm}}{\delta \gamma^m}\frac{\delta \gamma^m}{\delta \beta_1{}^m}\right)\right] \tag{19}$$

Player 1 will be maximizing the gains from misreporting, π^m, by choosing to report the discount factor and thus $\beta_1{}^m$ that yields the highest utility. This is done also keeping weights such that player 1 is at least not worse off cooperating compared to competing, and player 2 believes he is at least not worse off cooperating than competing. Algebraically, this is:

$$\mathrm{Max}_{\beta_1{}^m}: \pi^m = V_1^C(\gamma^m) - V_i^C(\gamma) \tag{20}$$

Subject to:

$$V_1^C(\gamma^m, \delta) \geq V_1^N(\delta) \tag{21}$$

and

$$V_2^C(\gamma^m, \delta^m) \geq V_2^N(\delta^m) \tag{22}$$

Further derivation of the optimal $\beta_1{}^m$ is found in appendix 3, but software using these objective functions is used to simulate results, shown in the next section.

Nash bargaining

Using instead the Nash bargaining solution, as in Rettieva (2013), weights are set by maximizing the product of believed gains from cooperation for each player.

$$Max_{\gamma}\ \Pi^{Cm} = \left[V_1^C(\gamma^m, \delta^m) - V_1^N(\delta_i^m)\right]\left[V_2^C(\gamma^m, \delta^m) - V_2^N(\ \delta_i^m)\right] \tag{23}$$

$$= [A_1^C(\gamma^m, \delta^m) - A_1^N(\ \delta^m)][A_2^C(\gamma^m, \delta^m) - A_2^N(\ \delta^m)]$$

$$= \left[(1-\delta_1{}^m)^{-1}\left(log\, h_1^{Cm} + \beta_1{}^m \log q^{Cm}\right) - (1-\delta_1{}^m)^{-1}(log\, h_1^{Nm} + \beta_1{}^m \log q^{Nm})\right]\left[(1-\delta_2{}^m)^{-1}\left(log\, h_2^{Cm} + \beta_2{}^m \log q^{Cm}\right) - (1-\delta_2{}^m)^{-1}(log\, h_2^{Nm} + \beta_2{}^m \log q^{Nm})\right]$$

The previous constraints, i.e. equations (21) and (22), must also hold here. Again, results are shown using software and further derivation of weights and optimal reports are found in appendix 3.

Effects of misreporting

First, the various effects of misreporting the discount factor will be shown. The optimal strategy of player 1 will then be found showing the gains from misreporting different values of the discount factor. This will be done with different combinations of actual discount factors, growth of the fish stock and how the weights are decided. When showing the numerical results, the true discount factors will be either 0.99 or 0.8, and reported values of the discount factor range from 0.99 to 0.5. A player with a discount factor of 0.99 is referred to as patient and a player with a discount factor of 0.8 is referred to as an impatient player. No moral standpoint is taken as differing discount factor only present differing objectives of the management of the resource.

In both cases when misreporting affects the weights, harvest levels are affected in two ways. Firstly, a lower reported discount factor results in a cooperation with a higher combined level of $\sum_{i=1}^{n} h_i^{Cm}$, which is a larger proportion of the stock harvested each year. Secondly, misreporting the discount factor also affect the individual harvesting shares, in such a way that a lower reported discount factor results in a higher share of the harvest. For the case of exogenous weights, only the first effect is present.

A graphical illustration of the effects of misreporting is shown in figure 1. Player 1 reporting a lower discount factor results in a higher weight and thus a higher share of the harvest. At the same time, the part of the stock that is harvested by the coalition is also increased, which decreases the equilibrium level of the stock. This results in lowering the equilibrium harvest for both players. For the harvest of player 2, the two effects are negative. The harvest for player 2 is thus strictly decreasing as player 1 reports a lower discount factor. For player 1, the two effects are opposing. Note also that maximizing utility and maximizing the equilibrium level of harvest is not the same, because of the discounting giving more weight to immediate harvest. A higher level of h_1 than that which maximizes equilibrium harvest is then desired.

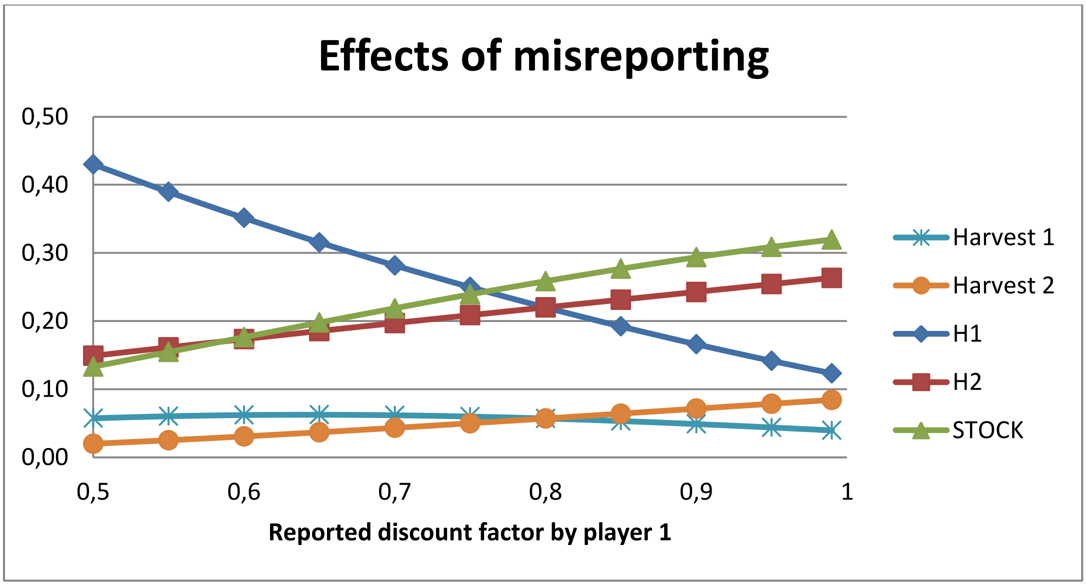

Figure 1. Effects of misreporting discount factor. (Nash bargaining, α=0.7; δ_1=δ_2=0.8)

From figure 2, it is clear that for lower values of the reported discount factor, the weight for player 1 is higher. The effects on the utility of player 2 are positively related with the reported discount factor of player 1. The effect on player 1's own utility is negatively related to the reported discount factor. Reporting a lower discount factor yields a higher utility.

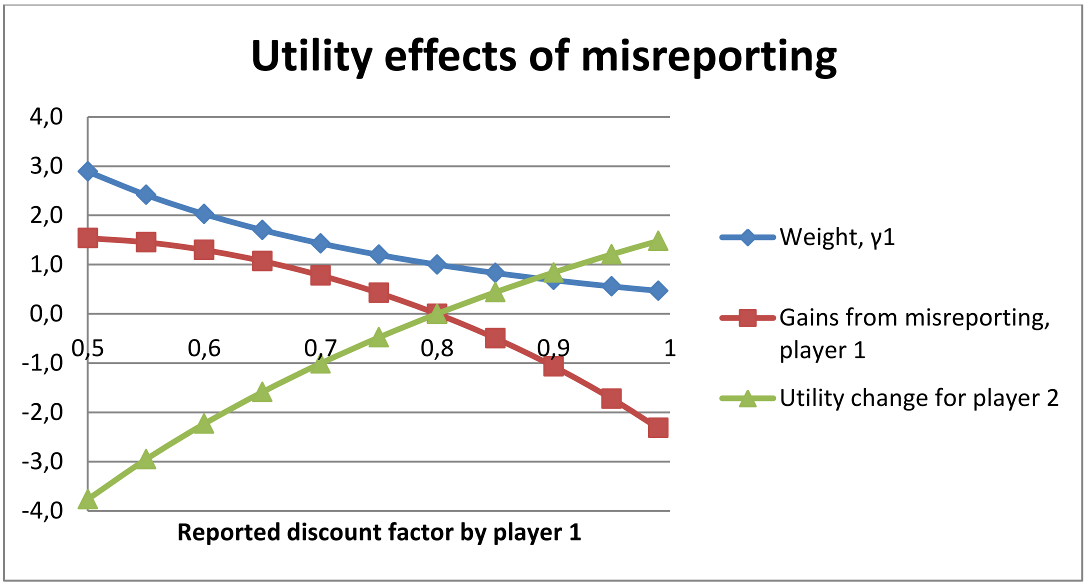

Figure 2. Utility effects of misreporting. (Nash bargaining, α=0.7; δ_1=δ_2=0.8)

For different combinations of true discount factors and growth rates of the stock, the utility gains of player 1 are shown in figures 3 through 10. The first four figures illustrate results from Nash bargaining while the last four illustrate results from the scenario where player 2 proposes the weights.

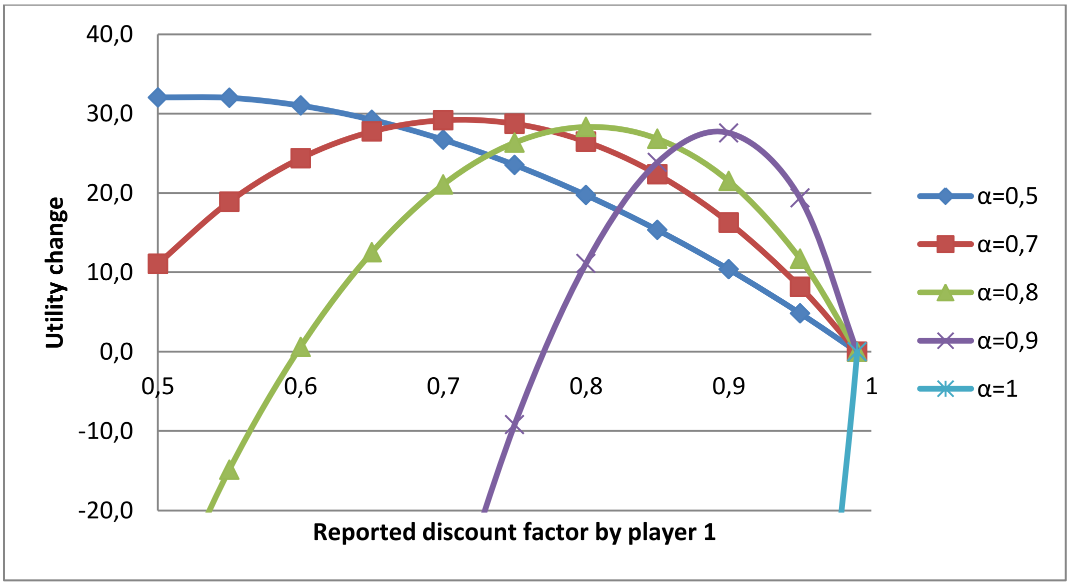

Figure 3. Gains from misreported levels of the discount factor. (Nash bargaining, δ_1=0.99, δ_2=0.99)

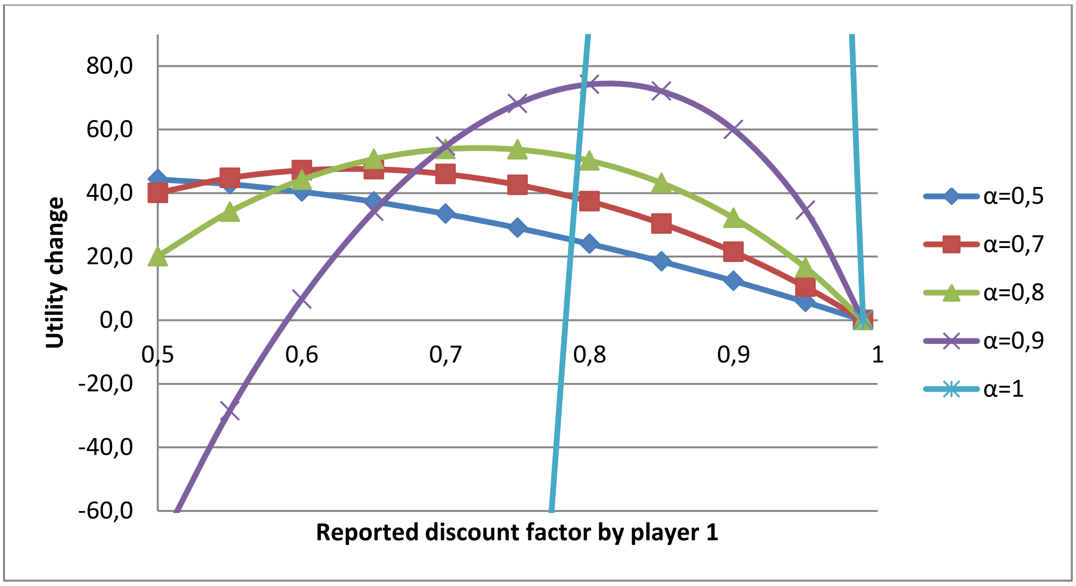

Figure 4. Gains from misreported levels of the discount factor. (Nash bargaining, δ_1=0.99, δ_2=0.8)[2]

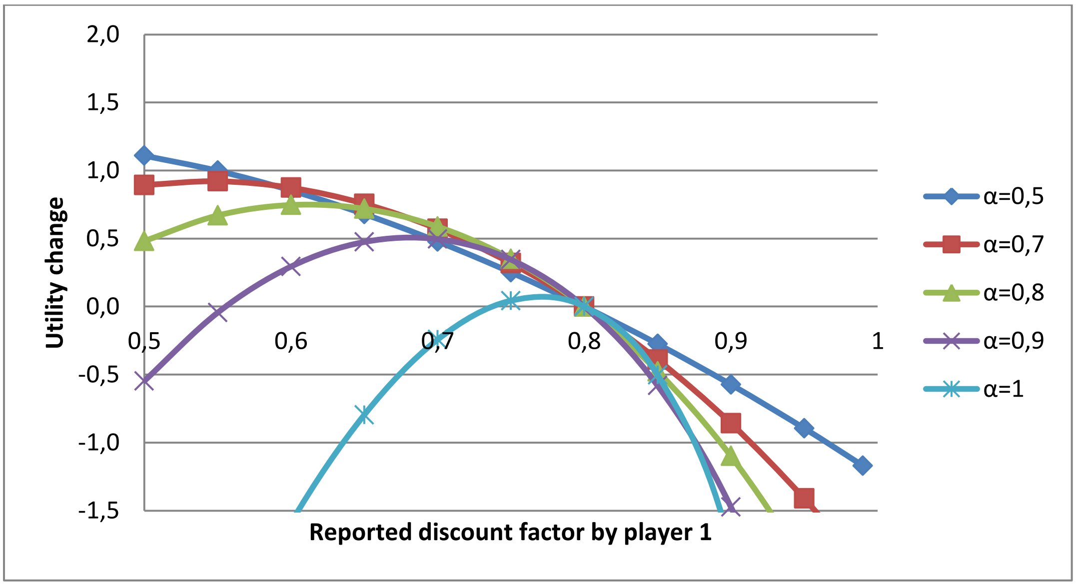

Figure 5. Gains from misreported levels of the discount factor. (Nash bargaining, d1=0.8, d2=0.99)

[2] When α is 1, the gain from the optimal report is around 450. A graph with expanded y-axis can be found in the appendix.

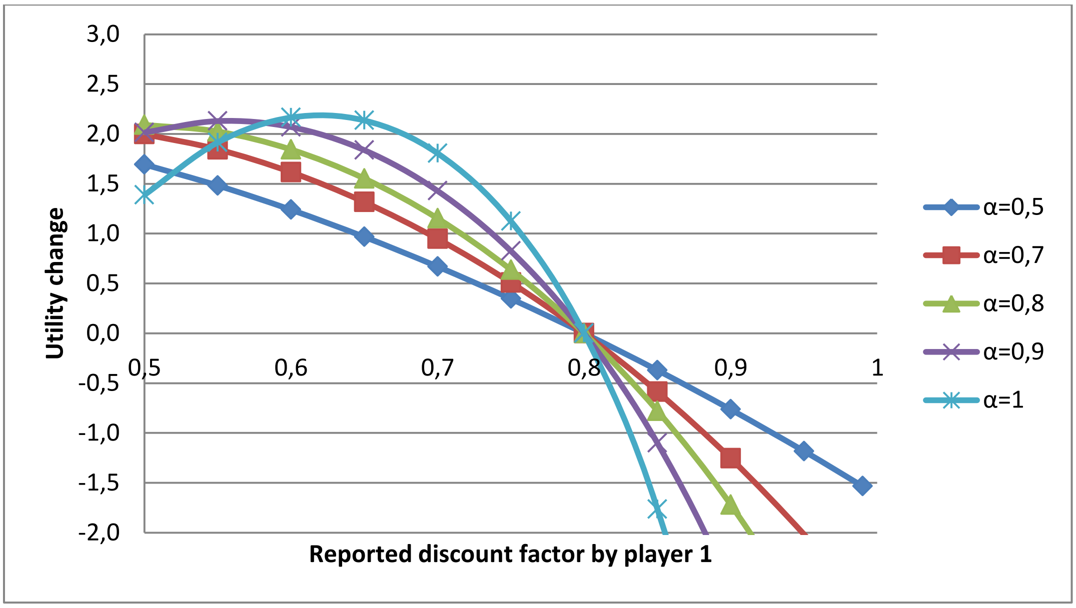

Figure 6. Gains from misreported levels of the discount factor. Nash bargaining, d1=0.8, d2=0.8

The benefits of misreporting time preferences are concave in the reported discount factor. There exists an optimally reported factor, and this is in most cases below the actual value. It is only non-beneficial to misreport the discount factor when the resource has low growth potential. For misreporting not to be beneficial, both countries have to be relatively patient as well, using high actual discount factors. In all of figures 3 through 6, when α increases, the optimally reported discount factor increases as well. If there is less growth in the resource, reporting closer to the actual discount factor is optimal.

Comparing figure 3 and 4, or 5 and 6, we can also tell that when the discount factor of player 2 is higher, player 1 will misreport closer to the actual value. By comparing figure 3 and 5, or 4 and 6, we can conclude that when the discount factor of player 1 is higher, the misreport will again be closer to the actual value.

Graphs 7 to 10 show gains from misreported levels of the discount factor when player 2 is deciding how to allocate the weights. The shapes and trends are the same as with bargaining, with the difference that optimally reported discount factor is slightly pushed further away from the true value in the case where player 2 decides weights.

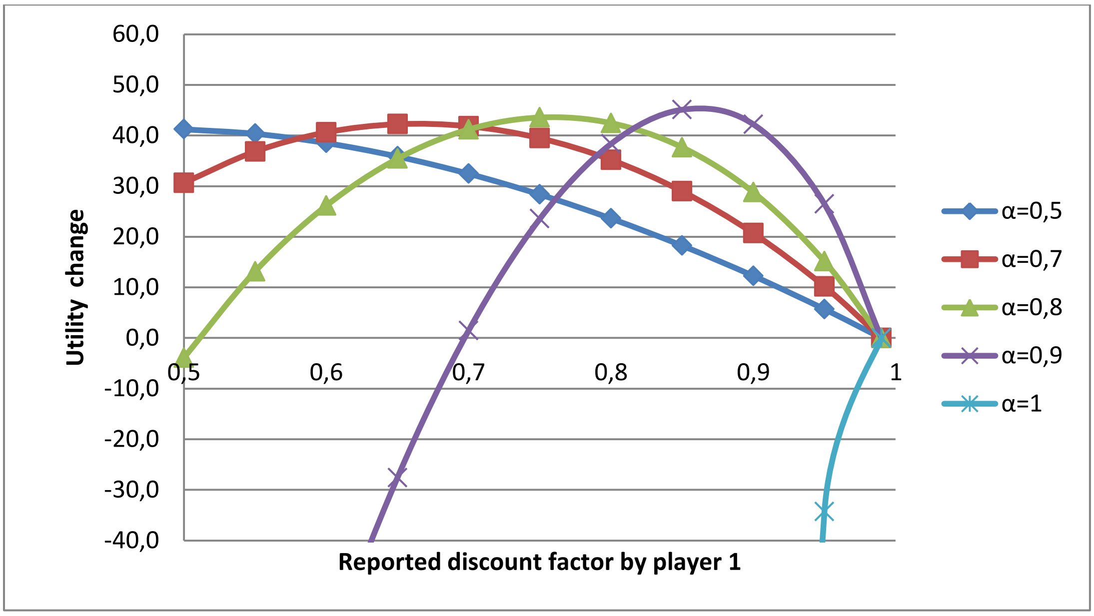

Figure 7. Gains from misreported levels of the discount factor. (Player 2 deciding weights, d1=0.99, d2=0.99)

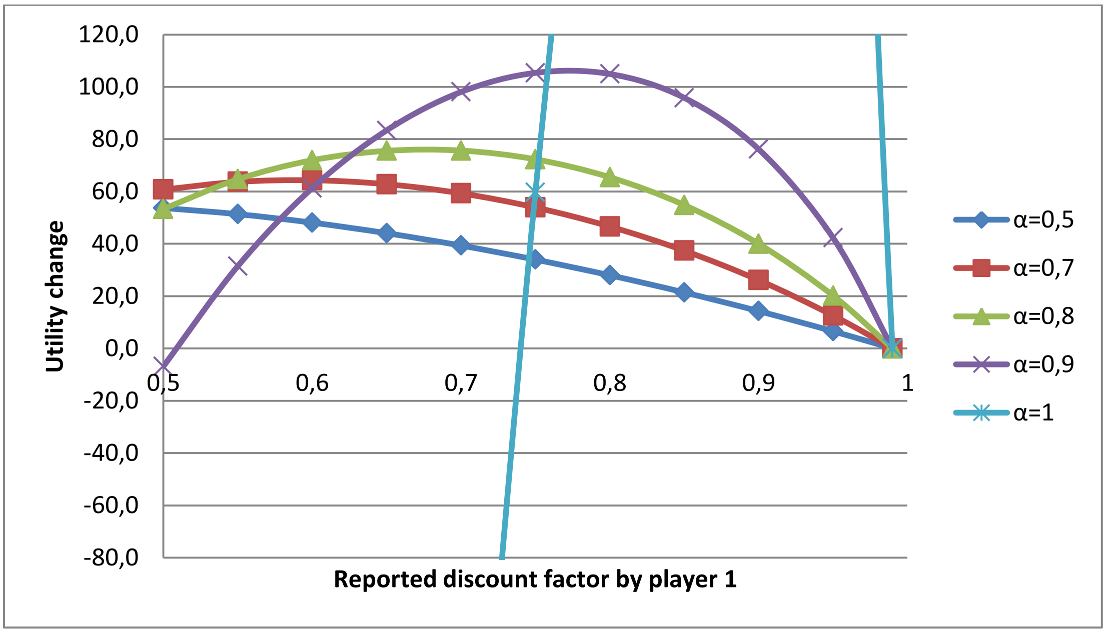

Figure 8. Gains from misreported levels of the discount factor. (Player 2 deciding weights, d1=0.99 , d2=0.8)[3]

[3] As before, when α is 1, the gain from the optimal report is around 530. A graph with expanded y-axis can be found in appendix 5.

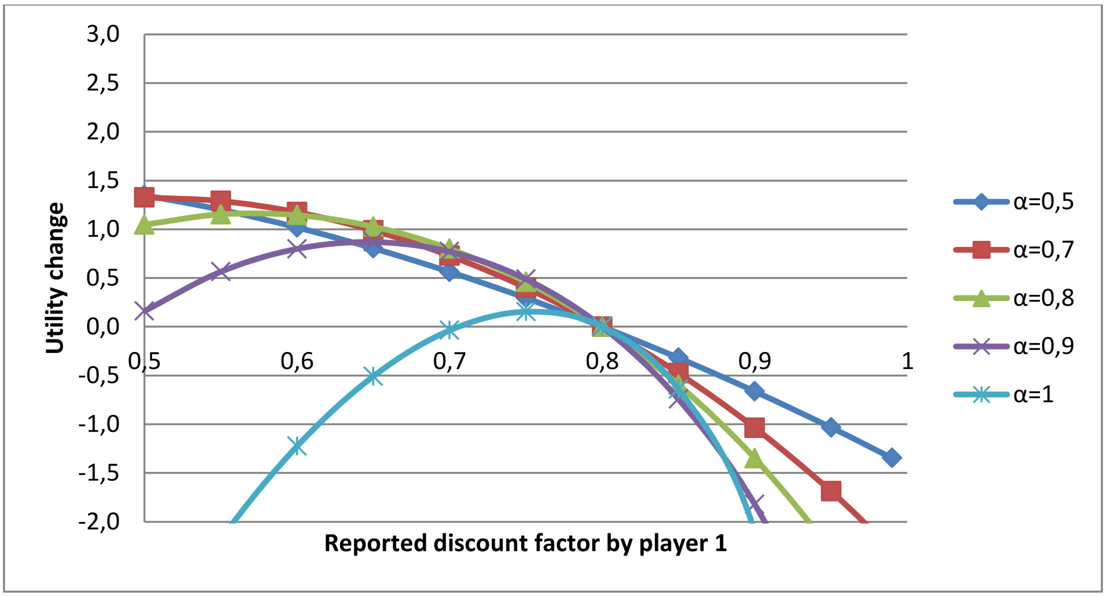

Figure 9. Gains from misreported levels of the discount factor. (Player 2 deciding weights, d1=0.8 , d2=0.99)

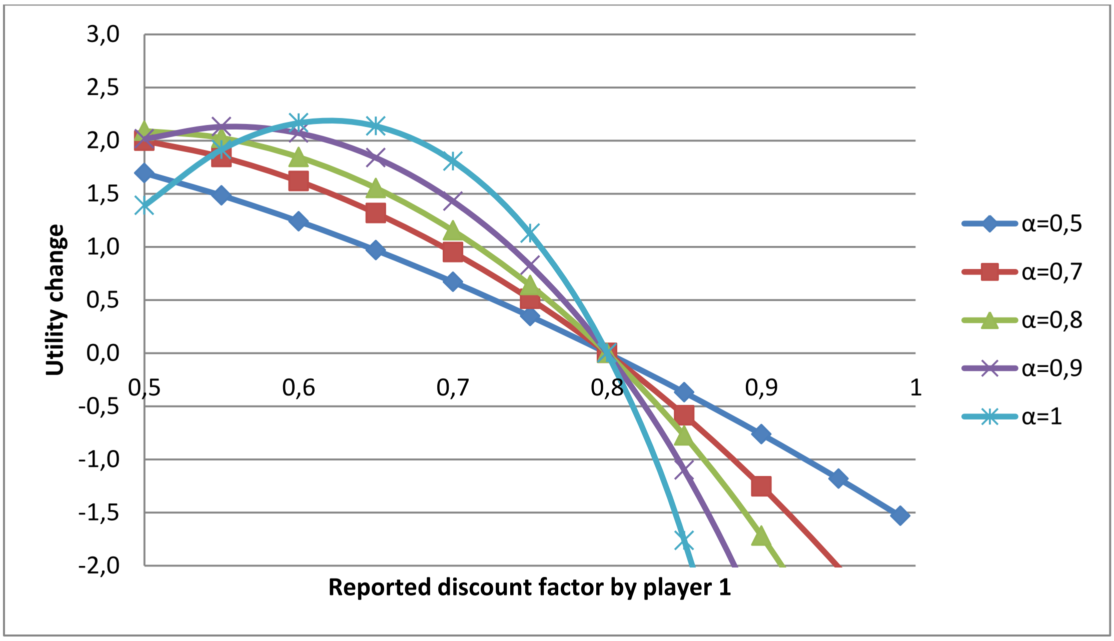

Figure 10. Gains from misreported levels of the discount factor. (Player 2 deciding weights, d1=0.8 , d2=0.8)

A second-best policy to avoid misreporting

In order to deter misreporting by player 1, player 2 may design a second best policy. Imagine an incumbent country or collusion of countries already managing a fish pool. At the presence of a new entrant contemplating harvesting the resource, the incumbent party may propose to the entrant how the management is to be set up and how the harvest is divided. In the case of large scale fishing in international waters, this would not be an unlikely situation. The time preferences, and thus management objectives, of the entrant could be unknown whilst an incumbent player has already revealed time preferences with past management of the resource. The information asymmetry could be further justified by having one player being a country with a stable economy, where for instance economic growth is expected to be steady. The management objectives, or time preferences, of such a country would likely be publicly known. Meanwhile, if the other player is a country where the state of the economy is volatile and/or characterized by relevant but hardly assessable political risks, the actual time preferences of this country would not be public knowledge. Some level of misreporting would then be possible.

The second-best policy should ensure both cooperation and truthful reports. In this section, such a policy is examined in a Stackelberg frame where player 2 leads and proposes a weight to player 1. Player 1 will then accept this deal or reject it, resulting in competitive outcomes. For the sake of simplicity but at no loss in terms of intuition, the analysis will be developed in a two-type frame. A description of the model as well as notes on the continuous frame can be found in Laffont and Martimort (2002). The players may either be patient, using $\overline{\delta}$ as discount factor, or impatient, using $\underline{\delta}$. The weights will be set by player 2, who will, in the following, be referred to as the Principal, after the report given by player 1, who is referred to as the Agent. The Agent may report being either of type $\overline{\delta}$ or $\underline{\delta}$.

If there is no information asymmetry, weights will be set such that the utility of cooperation and competition are the same for the Agent. This should be done in order to secure that cooperation is achieved at the lowest cost for the Principal. When the type of the Agent is private information, however, the Principal has to offer a menu of weights that ensures that the Agent will reveal his true discount factor, and also prefer cooperation over competition. These requirements can be met by imposing two constraints for each possible type of player. The incentive compatibility constraints ensure that each type of player prefers revealing their true time preferences over misreporting. This is:

$$V_1{}^C(\overline{\delta},\overline{\gamma_{1SB}}) > V_1{}^C\left(\overline{\delta},\underline{\gamma_{1SB}}\right) \tag{24}$$

and

$$V_1{}^C\left(\underline{\delta},\underline{\gamma_{1SB}}\right) > V_1{}^C(\underline{\delta},\overline{\gamma_{1SB}}) \tag{25}$$

The discount factor in parenthesis represents the true value and the gamma is the established weight, based on the report given by the Agent. Subscript SB is for the second-best policy.

The individual rationality constraints ensure that each type of player also prefers cooperation under the proposed contract over competition. This is:

$$V_1{}^C(\overline{\delta},\overline{\gamma_{1SB}}) > V_1{}^N(\overline{\delta}) \tag{26}$$

and

$$V_1{}^C\left(\underline{\delta},\underline{\gamma_{1SB}}\right) > V_1{}^N(\underline{\delta}) \tag{27}$$

As long as cooperating is preferred over competition, the Principal will maximize his utility by proposing the lowest weights for the Agent that still meet these constraints. The maximized expected utility of the Principal is:

$$\max_{\overline{\gamma_{1SB}},\underline{\gamma_{1SB}}} P * V_2{}^C(\overline{\delta},\overline{\gamma_{1SB}}) + (1-P) * V_2{}^C\left(\underline{\delta},\underline{\gamma_{1SB}}\right) \tag{28}$$

P is the probability that the Agent is of type $\overline{\delta}$. The true discount factor of the Agent is unknown to the Principal, but the probability distribution, and thus P, is known.

Since a player of type $\overline{\delta}$ may have incentives to report $\underline{\delta}$, the weight proposed for a report of $\overline{\delta}$ may have to be higher in the second-best policy than in the first-best scenario. The difference between first-best and second-best weights is the informational rent.

All of the constraints will not be binding at the optimum. The problem of asymmetric information lays in that a patient player may report being more impatient. This type of player must then be given an information rent in order to stay truthful, whereas the impatient player only needs to be given a weight such that competition is not preferred. Hence, we must have the equalities:

$$V_1{}^C(\overline{\delta},\overline{\gamma_{1SB}}) = V_1{}^C\left(\overline{\delta},\underline{\gamma_{1SB}}\right) \tag{29}$$

and

$$V_1{}^C\left(\underline{\delta},\underline{\gamma_{1SB}}\right) = V_1{}^N(\underline{\delta}) \tag{30}$$

The second restriction (equation 25) will not be binding since it is only beneficial to misreport a lower discount factor. The third restriction is likely not binding either, since $\overline{\gamma_{1SB}}$ will have to be increased compared to $\overline{\gamma_{1FB}}$ due to the first restriction. The problematic restriction for the Principal is the first one, and the difference ${V_1}^C\left(\overline{\delta}, \underline{\gamma_{1FB}}\right) - {V_1}^C\left(\overline{\delta}, \overline{\gamma_{1FB}}\right)$ is what must be compensated for in the second-best policy by giving a higher weight for a report of $\overline{\delta}$.

Proposition 2. *Under asymmetric information, the optimal set of weights proposed entails:*

- No weight distortion for the impatient type $\underline{\delta}$, with respect to the first-best solution. An upward distortion of the weights for the patient type $\overline{\delta}$. The distortion observed represents the information rent to be paid for securing incentive compatibility.

- Only the patient type gets a strictly positive utility change, given by:

$$ {V_1}^C\left(\overline{\delta}, \underline{\gamma_{1FB}}\right) - {V_1}^C\left(\overline{\delta}, \overline{\gamma_{1FB}}\right) \tag{31} $$

Assuming the Principal has the discount factor $\overline{\delta}$ = 0.99, $\underline{\delta}$ is 0.8 and α is 0.7, numerical results are as follows in table 1. In the table, weights proposed and corresponding utilities are shown for the case of no policy and the second-best policy. Values are shown for the two levels of discount factor, with the same two possible levels of reported discount factor. The first-best policy weights and values are found in the 3rd through 5th row in the columns where reporting is truthful. Bold numbers are the values associated with the best response for the Agent.

Table 1. Results of policies. δ_2=0.99, α=0.7

δ_1	0.8		0.99	
${\delta_1}^m$	0.8	0.99	0.8	0.99
γ_1	1.602	0.718	1.602	0.718
$V_1(\delta^m, \gamma)$	**-11.1**	-13.4	**-254.0**	-289.4
$V_2(\delta^m, \gamma)$	**-301.2**	-256.2	**-301.2**	-256.2
γ_{1SB}	1.602	1.47	1.602	1.47
$V_1(\delta^m, \gamma_{SB})$	**-11.1**	-11.6	-254.0	**-254.0**
$V_2(\delta^m, \gamma_{SB})$	**-301.2**	-292.5	-301.2	**-292.5**
${V_2}^N$	-343.6		-289.2	

If the Agent has a discount factor of 0.8, the weight has to be at least 1.602. Anything lower will make competition preferred. If the Agent has a discount factor of 0.99, the weight has to be 0.718 or higher. However, an Agent with 0.99 will prefer reporting 0.8 and be given a weight of 1.602, since this gives a higher utility (-254.0 compared to -289.4). To avoid this misreporting, the Principal has to raise the weight given for a reported discount factor of 0.99 up to 1.47. This makes the Agent indifferent between staying honest and misreporting, if the true discount factor is 0.99. If the discount factor of the Agent is 0.8, reporting 0.8 is still preferred over reporting 0.99. Using this policy, the utility of the Principal will be -301.2 if the Agent has a discount factor of 0.8, and -256.2 if the Agent has a discount factor of 0.99. These utilities should also be compared to the competitive outcomes. If competing, the Principal will have a utility of -343.6 if the Agent has a discount factor of 0.8 and -289.2 if the Agent has a discount factor of 0.99. The policy is thus working in keeping the Agent truthful, without incurring losses for the Principal compared to the competitive outcomes. To find the informational rent we compare the weights in the first-best scenario with those in the second-best. In the case of an impatient Agent ($\delta_2 = 0.8$), the weights are the same and there is no informational rent. For the patient Agent ($\delta_2 = 0.99$) the first best weight is 0.718 and the second best weight is 1.47. The informational rent is then $1.47 - 0.718 = 0.752$.

Results when the Principal instead has a discount factor of 0.8 are shown in table 2 and results when the growth potential is limited are shown in table 3, where α is changed to 0.9.

Table 2. Results of policies. $\boldsymbol{\delta_2}$=0.8, $\boldsymbol{\alpha}$=0.7

δ_1	0.8		0.,99	
${\delta_1}^m$	0.8	0.99	0.8	0.99
γ_1	0.775	0.345	0.775	0.345
$V_1(\delta^m, \gamma)$	**-12.749**	-15.452	**-297.017**	-343.631
$V_2(\delta^m, \gamma)$	**-11.474**	-10.133	**-11.474**	-10.133
γ_{1SB}	0.775	0.666	0.775	0.666
$V_1(\delta^m, \gamma_{SB})$	**-12.749**	-13.289	-297.017	**-297.017**
$V_2(\delta^m, \gamma_{SB})$	**-11.474**	-11.258	-11.474	**-11.258**
${V_2}^N$	-12.749		-11.124	

If the Principal has a discount factor of 0.8, the second-best policy will be beneficial if the Agent has a discount factor of 0.8, but the Principal will actually prefer competing if the Agent´s true discount factor is 0.99. This is because the weight needed to keep an Agent of type $\overline{\delta}$ truthful is simply too high for the Principal to benefit from the cooperation. If the Principal is risk neutral and the probability distribution of the type of the Agent is uniform, the Principal will still use the second best policy, since the expected benefit is positive:

$$E\left[V_2\left(\delta^m, \gamma_{SB}\right) - {V_2}^N\right] > 0 \qquad (32)$$

$$0{,}5 * [(-11{,}474) - (-12{,}749)] + 0{,}5 * [(-11{,}258) - (-11{,}124)] = 0{,}5705 \qquad (32.1)$$

Table 3. Results of policies. $\boldsymbol{\delta_2}$=0.99, $\boldsymbol{\alpha}$=0.9

δ_1	0.8		0.99	
${\delta_1}^m$	0.8	0.99	0.8	0.99
γ_1	28.639	0.591	28.639	0.591
$V_1(\delta^m, \gamma)$	**-14.389**	-26.634	-1051.339	**-607.643**
$V_2(\delta^m, \gamma)$	**-1386.817**	-555.069	-1386.818	**-555.069**
${V_2}^N$	-1659.611		-607.643	

When the growth potential is more limited, with α=0.9, the second best policy is not needed. The Agent already prefers reporting truthfully and both players prefer the proposed cooperative management over the competitive outcome.

The set-up of the second-best policy clearly depends on discount factors, possible levels of reported discount factors and the growth potential of the stock. It seems that the second-best policy is more worth-while for a patient Principal and it is less beneficial if the Agent is, or has a high probability of being, a patient player. Since a lower growth potential of the resource diminish the range of beneficial misreported values of the discount factor, a lower growth rate will make the second-best policy less likely to be needed.

In the second-best policy examined, only the Agent has had the misreporting potential. The justification was an incumbent Principal, whose time preferences were already revealed by past management of the fish stock. Including misreporting potential for the Principal would be an interesting addition but will be left aside for possible future studies. A short analysis of having both players misreporting, with equal bargaining power, follows in the next section.

Both players misreporting

So far, only player 1 has had the potential to misreport time preferences. Now, we shall see the outcomes when also giving player 2 the option of misreporting time preferences. The weights will be set by the Nash bargaining procedure. Both players are thus equal in every aspect, except they may differ in their true time preferences. In the setup, the players can only choose between a few levels of the reported discount factor. Table 4 and 5 show the outcomes in terms of what the players gain or lose from misreporting. Bold numbers show best response and optimal report. For the values of true discount factors and growth potentials of the stock used, there are individual incentives to report the lowest discount factor. This is however damaging for both players when they both have a discount factor of 0.9, since they would be better off if both reported the true values. When one player is more patient than the other, using discount factors of 0.99 and 0.8, both will have incentives to report the lower option, increasing the utility of the patient player but damaging that of the more impatient player. At the same time, equilibrium level of the stock is lowered, as a result of reporting lower discount factors.

Table 4. Gains from reported discount factors. Nash bargaining, α=0.7, δ1=δ2=0.9

		Player 1		
	δ_i^m	**0.8**	0.9	0.99
	0.8	(**-0.27, -0.27**)	(-2.17, **1.64**)	(-4.52, **3.08**)
Player 2	0.9	(**1.64**, -2.17)	(0,0)	(-2.12, 1.67)
	0.99	(**3.08**, -4.52)	(1.67, -2.12)	(-0.24, -0.24)

Table 5. Gains from reported discount factors. Nash bargaining, α=0.7, δ1=0.8, δ2=0.99

		Player1	
	δ_i^m	**0.8**	0.99
Player 2	**0.8**	(-**1.48**, **37.42**)	(-3.8, **75.98**)
	0.99	(**0**,0)	(-1.92, 49.53)

Conclusion

It has been shown that misreporting time preferences can be beneficial for individual players in the management of a common fish pool. Optimal reporting is affected by the discount factors of each player. A higher factor for any player results in an optimal report closer to the actual factor. A higher α, which is a lower regeneration rate of the resource, also leads to the optimal report being closer to the actual value. How the weights are decided in the collusion also affect optimal reporting, but the general shapes and trends are the same as long as misreporting affects the weights. When weights are exogenous, reporting a discount factor in the opposing direction compared to the discount factor of the other player is the optimal behavior. When reporting a lower discount factor, which is the only beneficial misreport in the case of endogenous weights, equilibrium level of the stock is lowered and so is the equilibrium level of harvest. This is then damaging the social welfare. In order to avoid misreporting, one of the players may design a second-best policy. This has been shown to possibly increase the utility of the truthful player, but is not always guaranteed to work in keeping the other player truthful at the same time as keeping cooperation preferred over competition. When both players have the potential to misreport their time preferences, a prisoners' dilemma can evolve and both players report a lower discount factor, damaging equilibrium stock levels, harvests and utility for both players.

Hiding time preferences may not only impact the performance of a cooperative agreement in terms of levels of harvest, but may also make cooperating less beneficial. This may then, by potentially hindering cooperation, be a threat for the sustainable management of fish species over. In order to secure the future of these species and the welfare accruing through the harvest, understanding cooperation is important. Misreporting preferences may, in spite of being detrimental for the management of the fish stock and for achieving a socially optimal level of welfare, emerge as a dominant strategy for individual Agents. This is a problem, and understanding the drivers for decision making may help reduce the risks of exhausting fish stocks as well as improving welfare.

In real life, no negotiations are as simple as two players reporting their discount factor with outcomes then being decided according to a certain bargaining method. However, countries do differ in their management objectives and the discount factor can be used as a proxy for these management objectives.

In 1994, members of the North-west Atlantic Fisheries Organization (NAFO) decided to put a 27 000t upper limit on the amount of halibut caught in the high seas in the North West Atlantic (European Commission, 1995). The harvests had previously amounted to 40 000t and commitment to lower harvest was needed in order to conserve the fish stock. Once the upper limit was fixed, discussions began on how to share the quotas. The establishment of these shares then became an international issue, mainly concerning disagreement between the EU and Canada, since shares were drastically changed compared to how much was harvested before. In the model proposed in this thesis, no upper limit of the harvest is set, as was done by NAFO. However, adjustments could easily be made in order to replicate the procedure where the quotas were set for the halibut population in the North-West Atlantic. This would require a stage of the game where the total limit is set, either exogenously or according to given time preferences of countries involved.

Another cooperation between countries is the harvest agreement between Norway and Russia (Hanneson, 2007). Together the countries manage the cod stock in the Northeast Arctic. After setting aside a small share to third countries, harvests are split equally between Norwegian and Russian vessels. The total amount is then set each year. The procedure in this thesis is similar, but once reporting of the time preferences are made, the model determines shares and total harvests instantly. The agreement between Norway and Russia also suffer from quotas being cheated (Hanneson, 2007). Russia has likely been overfishing their quotas for several years, and this is a potential problem for every establishment of limits on how much to harvest. The problems with common fish pools are thus multiple and the management is a complex issue. Overfishing the quotas can, however, be avoided by extensive monitoring. In the North-west Atlantic, Canadian authorities occasionally inspected vessels as often as twice a week, drastically increasing the risk of being caught overfishing the quotas (European Commission, 1995). Cheating and monitoring would be an interesting aspect to include in the model. Monitoring comes with a cost, but a certain level would be required in order for everyone not to overfish and to keep the fish stock at sustainable levels.

The analysis of the problems associated with the misreport of time preferences is not only applicable to the cooperation in the management of a common fish pool. The analysis can in fact very well extend to the management of other resources characterized by a different level of renewability and more in general to the provision of public goods and services.

A sound example is given by the coordination for climate action. When discussing the cutting of Greenhouse gas emissions, each interested country desires a lower amount of total emissions. In order to reach this target, each country is supposed to contribute by lowering its own emissions. However, this action is costly and requires effort over several years. Hence, in the presence of incentives for hiding preferences, finding a solution to the standard free riding problem becomes even more challenging.

In conclusion, the impact of misreporting time preferences can, sadly, be a much wider issue affecting not only the management of fish stocks. Management of common fish pools can, however, serve as an effective representation of the issue, which once again, may emerge within any context where the set-up of a coalition may secure welfare improvements.

Appendix

Appendix 1. Second derivative of gains from misreporting

The second derivative of the gains from misreporting for player 1 with respect to the misreported level, when minimizing the weight for player 1, is:

$$\frac{\delta^2\pi^m}{\delta{\beta_1}^{m2}} = -\frac{{\gamma_1}^2\left(-{\beta_2}^2 + 2\beta_2(\gamma_1\beta_1 - {\gamma_1}^m\,{\beta_1}^m + \beta_1) - {\gamma_1}^2{\beta_1}^{m2}(\gamma_1+1)\beta_1(2\gamma_1{\beta_1}^m + \gamma_1 + 1)\right)}{(\beta_2 + \gamma_1{\beta_1}^m)^2(\beta_2 + \gamma_1{\beta_1}^m + \gamma_1 + 1)^2} \qquad \text{(A.1)}$$

Appendix 2. The optimally proposed weight

Player 2 proposes the weight that makes player 1 indifferent between cooperation and competition. This gives:

$$V_1^C(\gamma^m, \delta^m) = V_1^N(\delta_i^m) \qquad \text{(A.2)}$$

$$A_1^C(\gamma^m, \delta^m) + (1 + {\beta_1}^m)\log s = A_1^N(\delta^m) + (1 + {\beta_1}^m)\log s$$

$$A_1^C(\gamma^m, \delta^m) = A_1^N(\,\delta^m)$$

$$(1-\delta^m)^{-1}\left(log\,h_1^{Cm} + {\beta_1}^m \log q^{Cm}\right) = \left(1 - {\delta_i}^m\right)^{-1}\left(log\,h_1^{Nm} + {\beta_1}^m \log q^{Nm}\right)$$

$$\left(log\,h_1^{Cm} + {\beta_1}^m \log q^{Cm}\right) = \left(log\,h_1^{Nm} + {\beta_1}^m \log q^{Nm}\right)$$

$$\frac{h_1^{Cm}}{h_1^{Nm}} = \left(\frac{q^{Nm}}{q^{Cm}}\right)^{{\beta_1}^m}$$

$$\left(\frac{{\gamma_1}^m}{({\gamma_1}^m + 1)}\frac{1}{\frac{({\gamma_1}^m{\beta_1}^m + \beta_2)}{({\gamma_1}^m + 1)} + 1}\right)\Bigg/ h_1^{Nm} = \left(q^{Nm}\Bigg/\frac{\frac{({\gamma_1}^m{\beta_1}^m + \beta_2)}{({\gamma_1}^m + 1)}}{\frac{({\gamma_1}^m{\beta_1}^m + \beta_2)}{({\gamma_1}^m + 1)} + 1}\right)^{{\beta_1}^m}$$

$$\frac{{\gamma_1}^m}{h_1^{Nm}\left({\gamma_1}^m{\beta_1}^m + \beta_2 + {\gamma_1}^m + 1\right)} = \left(q^{Nm} + \frac{q^{Nm}({\gamma_1}^m + 1)}{({\gamma_1}^m{\beta_1}^m + \beta_2)}\right)^{{\beta_1}^m}$$

And the optimally proposed weight is then:

$$\gamma_1{}^m = \left(q^{Nm} + \frac{q^{Nm}(\gamma_1{}^m + 1)}{\left(\gamma_1{}^m \beta_1{}^m + \beta_2\right)} \right)^{\beta_1{}^m} h_1^{Nm}\left(\gamma_1{}^m \beta_1{}^m + \beta_2 + \gamma_1{}^m + 1\right) \tag{A.2.1}$$

Appendix 3. Deriving an optimal report

The derivative of the gains from misreporting with respect to $\beta_1{}^m$ is:

$$\frac{\delta \pi^m}{\delta \beta_1{}^m} = (1-\delta)^{-1} \left[\left(-\frac{\gamma_1{}^m}{(\gamma_1{}^m + 1 + \beta_2 + \gamma_1{}^m \beta_1{}^m)} + \frac{(1+\beta_2)}{\gamma_1{}^m (\gamma_1{}^m + 1 + \beta_2 + \gamma_1{}^m \beta_1{}^m)} \frac{\delta \gamma_1{}^m}{\delta \beta_1{}^m} \right) \right.$$
$$+ \beta_1 \left(\frac{\gamma_1{}^{m2} + \gamma_1{}^m}{(\gamma_1{}^m \beta_1{}^m + \beta_2)(\gamma_1{}^m + 1 + \beta_2 + \gamma_1{}^m \beta_1{}^m)} \right.$$
$$\left. \left. + \frac{\beta_1{}^m - \beta_2}{(\gamma_1{}^m \beta_1{}^m + \beta_2)(\gamma_1{}^m + 1 + \beta_2 + \gamma_1{}^m \beta_1{}^m)} \frac{\delta \gamma_1{}^m}{\delta \beta_1{}^m} \right) \right]$$

Optimizing gives:

$$-\gamma_1{}^m + \frac{(1+\beta_2)}{\gamma_1{}^m} \frac{\delta \gamma_1{}^m}{\delta \beta_1{}^m} + \beta_1 \left(\frac{\gamma_1{}^{m2} + \gamma_1{}^m}{(\gamma_1{}^m \beta_1{}^m + \beta_2)} + \frac{\beta_1{}^m - \beta_2}{(\gamma_1{}^m \beta_1{}^m + \beta_2)} \frac{\delta \gamma_1{}^m}{\delta \beta_1{}^m} \right) = 0$$

$$\beta_1 \left(\frac{\gamma_1{}^{m2} + \gamma_1{}^m}{(\gamma_1{}^m \beta_1{}^m + \beta_2)} + \frac{\beta_1{}^m - \beta_2}{(\gamma_1{}^m \beta_1{}^m + \beta_2)} \frac{\delta \gamma_1{}^m}{\delta \beta_1{}^m} \right) = \gamma_1{}^m - \frac{(1+\beta_2)}{\gamma_1{}^m} \frac{\delta \gamma_1{}^m}{\delta \beta_1{}^m}$$

$$\gamma_1{}^{m2} + \gamma_1{}^m + \beta_1{}^m \frac{\delta \gamma_1{}^m}{\delta \beta_1{}^m} - \beta_2 \frac{\delta \gamma_1{}^m}{\delta \beta_1{}^m} = \left(\gamma_1{}^m - \frac{(1+\beta_2)}{\gamma_1{}^m} \frac{\delta \gamma_1{}^m}{\delta \beta_1{}^m} \right) \left(\frac{(\gamma_1{}^m \beta_1{}^m + \beta_2)}{\beta_1} \right)$$

$$\beta_1{}^m \frac{\delta \gamma_1{}^m}{\delta \beta_1{}^m} = \left(\gamma_1{}^m - \frac{(1+\beta_2)}{\gamma_1{}^m} \frac{\delta \gamma_1{}^m}{\delta \beta_1{}^m} \right) \left(\frac{(\gamma_1{}^m \beta_1{}^m + \beta_2)}{\beta_1} \right) + \beta_2 \frac{\delta \gamma_1{}^m}{\delta \beta_1{}^m} - \gamma_1{}^{m2} - \gamma_1{}^m$$

$$\beta_1{}^m \frac{\delta \gamma_1{}^m}{\delta \beta_1{}^m} - \beta_1{}^m \left(\gamma_1{}^m - \frac{(1+\beta_2)}{\gamma_1{}^m} \frac{\delta \gamma_1{}^m}{\delta \beta_1{}^m} \right) \frac{\gamma_1{}^m}{\beta_1}$$
$$= \frac{\beta_2}{\beta_1} \left(\gamma_1{}^m - \frac{(1+\beta_2)}{\gamma_1{}^m} \frac{\delta \gamma_1{}^m}{\delta \beta_1{}^m} \right) + \beta_2 \frac{\delta \gamma_1{}^m}{\delta \beta_1{}^m} - \gamma_1{}^{m2} - \gamma_1{}^m$$

$$\beta_1{}^m = \frac{\frac{\beta_2}{\beta_1} \left(\gamma_1{}^m - \frac{(1+\beta_2)}{\gamma_1{}^m} \frac{\delta \gamma_1{}^m}{\delta \beta_1{}^m} \right) + \beta_2 \frac{\delta \gamma_1{}^m}{\delta \beta_1{}^m} - \gamma_1{}^{m2} - \gamma_1{}^m}{\frac{\delta \gamma_1{}^m}{\delta \beta_1{}^m} \left(1 - \left(\gamma_1{}^m - \frac{(1+\beta_2)}{\beta_1} \right) \right)}$$

$$\beta_1{}^m = \frac{\frac{\beta_2}{\beta_1}\left(\frac{\gamma_1{}^m}{\frac{\delta\gamma_1{}^m}{\delta\beta_1{}^m}} - \frac{(1+\beta_2)}{\gamma_1{}^m}\right) + \beta_2 - \frac{\left(\gamma_1{}^{m2} - \gamma_1{}^m\right)}{\frac{\delta\gamma_1{}^m}{\delta\beta_1{}^m}}}{\left(1 - \gamma_1{}^m + \frac{(1+\beta_2)}{\beta_1}\right)}$$

This is the optimally reported $\beta_1{}^m$. $\frac{\delta\gamma_1{}^m}{\delta\beta_1{}^m}$ is negative and depends on how the weights are decided, which is given by equations (A.2.1) and (A.4.1).

Appendix 4. The optimal weight in a Nash bargaining scenario

The objective function to be maximized by a collusion deciding weight according to the Nash bargaining procedure is:

$$Max_\gamma\ \Pi^{Cm} = \left[V_1^C(\gamma^m, \delta^m) - V_1^N(\delta_i^m)\right]\left[V_2^C(\gamma^m, \delta^m) - V_2^N(\delta_i^m)\right] \quad \text{(A.4)}$$

$$= [A_1^C(\gamma^m, \delta^m) - A_1^N(\delta^m)][A_2^C(\gamma^m, \delta^m) - A_2^N(\delta^m)]$$

$$= \big[(1-\delta_1{}^m)^{-1}\left(log\, h_1^{Cm} + \beta_1{}^m \log q^{Cm}\right) - (1-\delta_1{}^m)^{-1}(log\, h_1^{Nm} + \beta_1{}^m \log q^{Nm})\big]\big[(1-\delta_2{}^m)^{-1}\left(log\, h_2^{Cm} + \beta_2{}^m \log q^{Cm}\right) - (1-\delta_2{}^m)^{-1}(log\, h_2^{Nm} + \beta_2{}^m \log q^{Nm})\big]$$

Optimizing, with respect to $\gamma_1$gives:

$$\frac{\delta\pi^{Cm}}{\delta\gamma_1{}^m} = 0 \quad \text{(A.4.1)}$$

$$= \frac{\delta\, log\, h_1^{Cm}}{\delta\gamma_1{}^m}\frac{\left[(1-\delta_2{}^m)^{-1}\left(log\, h_2^{Cm} + \beta_2{}^m \log q^{Cm}\right) - (1-\delta_2{}^m)^{-1}\left(log\, h_2^{Nm} + \beta_2{}^m \log q^{Nm}\right)\right]}{1-\delta_1{}^m}$$

$$+ \frac{\delta\, log\, h_2^{Cm}}{\delta\gamma_1{}^m}\frac{\left[(1-\delta_1{}^m)^{-1}\left(log\, h_1^{Cm} + \beta_1{}^m \log q^{Cm}\right) - (1-\delta_1{}^m)^{-1}\left(log\, h_1^{Nm} + \beta_1{}^m \log q^{Nm}\right)\right]}{1-\delta_2{}^m}$$

$$+ \frac{\delta \log q^{Cm}}{\delta\gamma_1{}^m}\frac{\beta_1\left[(1-\delta_2{}^m)^{-1}\left(log\, h_2^{Cm} + \beta_2{}^m \log q^{Cm}\right) - (1-\delta_2{}^m)^{-1}\left(log\, h_2^{Nm} + \beta_2{}^m \log q^{Nm}\right)\right]}{1-\delta_1{}^m}$$

$$+ \frac{\delta \log q^{Cm}}{\delta\gamma_1{}^m}\frac{\beta_1{}^m\left[(1-\delta_1{}^m)^{-1}\left(log\, h_1^{Cm} + \beta_1{}^m \log q^{Cm}\right) - (1-\delta_1{}^m)^{-1}\left(log\, h_1^{Nm} + \beta_1{}^m \log q^{Nm}\right)\right]}{1-\delta_2{}^m}$$

where

$$\frac{\delta\, log\, h_1^{Cm}}{\delta\gamma_1{}^m} = \frac{\beta_2{}^m + 1}{\gamma_1{}^m(\beta_1{}^m\gamma_1{}^m + \beta_2{}^m + \gamma_1{}^m + 1)}$$

$$\frac{\delta \, log \, h_2^{Cm}}{\delta \gamma_1{}^m} = -\frac{\beta_1{}^m + 1}{\beta_1{}^m \gamma_1{}^m + \beta_2{}^m + \gamma_1{}^m + 1}$$

$$\frac{\delta \log q^{Cm}}{\delta \gamma_1{}^m} = \frac{\beta_1{}^m - \beta_2{}^m}{(\beta_1{}^m \gamma_1{}^m + \beta_2{}^m)(\beta_1{}^m \gamma_1{}^m + \beta_2{}^m + \gamma_1{}^m + 1)}$$

Appendix 5. Illustration of gains from misreporting

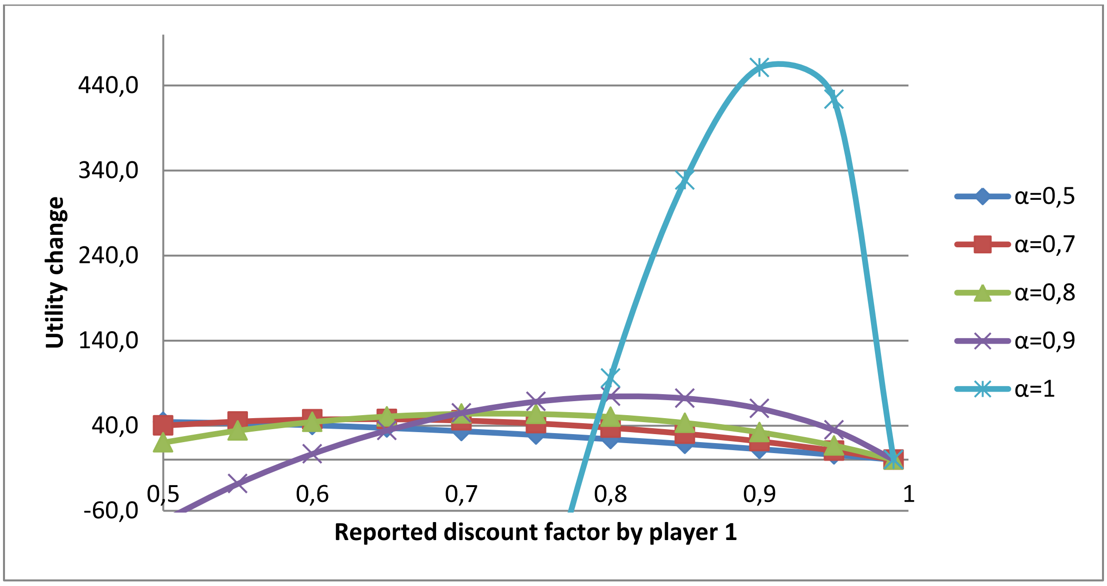

Figure A1, Gains from misreported levels of the discount factor. (Nash bargaining, $\boldsymbol{\delta_1}$=0.99, $\boldsymbol{\delta_2}$=0.8)

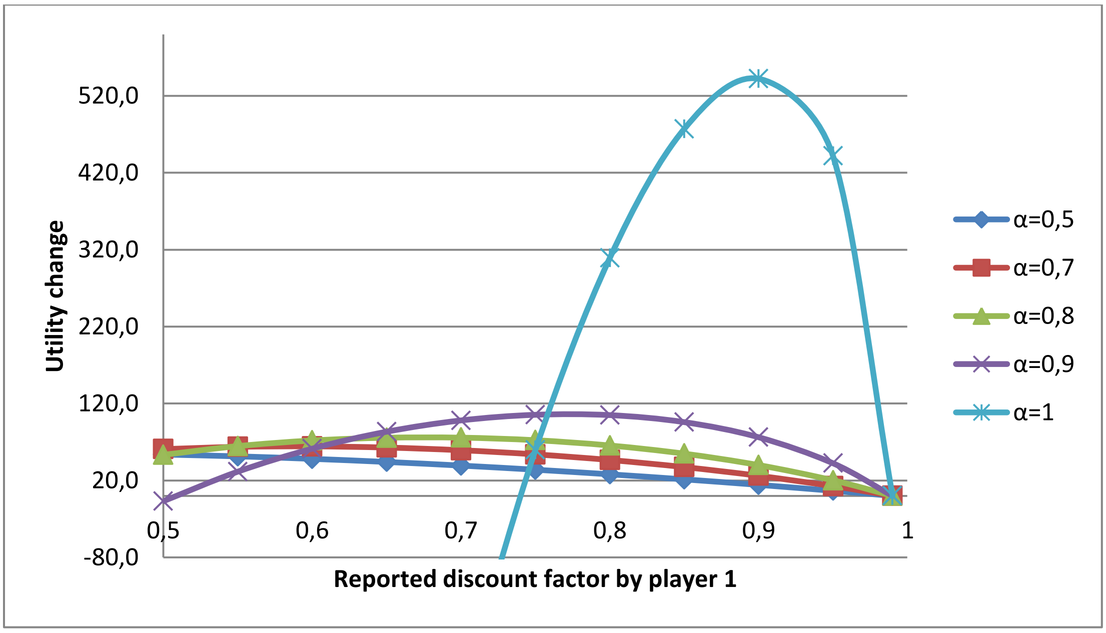

Figure A2, Gains from misreported levels of the discount factor. (Player 2 deciding weights, d1=0.99 , d2=0.8)

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