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Implicit Environmental Costs in Hydroelectric Development: An Analysis of the Norwegian Master Plan for Water Resources

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The ranking of hydropower projects under the Norwegian Master Plan for Water Resources is used to derive implicit government preferences for a number of environmental attributes described by ordinal scores for each project. We apply ordinal logistic regression to the ranks using the scores of the attributes as explanatory variables. As expected, we find that higher negative scores are generally associated with greater implicit willingness to pay to avoid the environmental damage tied to the attribute, caused by hydropower development. We derive total (ordinary economic and implicit environmental) costs for each project and find that environmental costs per capacity unit generally are lower than economic costs for projects ranked for early exploitation and higher for projects ranked for later development. Our derived implicit long-run marginal cost curve for Norwegian hydropower development is generally upward sloping, but not uniformly so. © 1993 Academic Press, Inc.

1. INTRODUCTION

In the present paper, we study the decision-making process behind the Norwegian Master Plan for Water Resources (hereafter called MP) and the implicit preferences for environmental aspects of river preservation, revealed through this process. The MP is described in Section 2. It is an ambitious and comprehensive plan, covering virtually all rivers in Norway that are today undisturbed and considered exploitable for hydropower purposes. Norway is rich in such resources, with the highest present electric power output per capita in the world, all of which is hydro based. In addition, there are exploitable reserves of more than 60 TWh (billion kWh) of annual capacity. This represents a considerable national resource, but the exploitation of more rivers has environmental consequences with impacts on wildlife, fish stocks, outdoor recreation, water supply, and the amount of undisturbed nature in general. The building of large dams, and the resulting changes in the courses of rivers, may also in many cases damage cultural monuments and impact adversely on agriculture, forestry, and reindeer herding.

Up until the late 1970s Norwegian hydropower was evaluated and developed project by project. However, increasing environmental concerns led to a decision

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by the Norwegian Parliament (the Storting) to design a comprehensive Master Plan for hydropower development. If this could be done in a consistent way among projects, one would thereby derive a "socially optimal" sequence of projects.

The work behind the MP consisted of the assignment of discrete scores to each of a number of specified user interests and regional economic impacts for each of about 540 projects. These impacts were weighed against the direct economic project costs. This resulted in a classification of the projects into 16 so-called *priority groups*, where lower-ranking groups are considered more suitable for exploitation.

The decision process itself was elaborate. It consisted of a major research effort and a complicated political process, involving various ministries and government agencies, private organizations, and finally the Norwegian Parliament. The main aim of this paper is to estimate the implicit valuations attached by decision makers to the various user interests, revealed through this decision process. In Section 3 we construct an ordinal logistic regression model for this purpose, where project priority is specified as a (linear) function of economic costs and of dummy variables related to the user interest and regional economy scores. We also estimated an ordinary least-squares (OLS) regression model with the same variables to investigate the robustness of the results to model specification. The results turned out to be very close for the two models. The resulting estimates for the logistic model are given in Section 4. As expected, we find that for the user interest variables, greater negative scores are associated with greater implicit environmental costs. Particularly high implicit valuations are attached to the "worst possible" scores for water supply and agriculture. Nature conservation, outdoor recreation, fish, and cultural monuments are all given high valuations. The model fits well to the data, with a multiple R^2 (adjusted) of 0.88 for the OLS regression model.

We calculated total implicit costs per expected output unit for each project by adding implicit environmental costs to direct economic costs. On the average, we find that implicit environmental costs comprise about 70% of the economic costs for projects in priority groups 1–5 (found most suitable for exploitation) and about 160% for all projects. This permits us to derive a long-run total marginal cost curve for Norwegian hydropower development. By and large, this curve is rising, but not uniformly so when considering individual projects, due to possible problems of model specification and to inconsistencies in the ranking process.

The present study is related to a few other recent studies trying to derive implicit valuations of environmental consequences from government decisions, in particular [3, 7, 8, 13]. These studies are based on various government decisions within one specific policy area. Here, by contrast, we derive implicit government preferences for environmental goods from one large-scale decision-making process. As such, this study appears to have no precedent.

Our approach is also somewhat related to that of multiobjective decision analysis, e.g., represented by the work of Keeney and Raiffa (see [6]), where decision makers and experts typically face the implicit valuation consequences of their stated policy choices and are subsequently allowed to adjust these. Here no such adjustments were possible, and the study is purely retrospective.

In the final Section 5 we discuss implications for subsequent Norwegian hydropower policy. Our derived long-run marginal cost of hydropower development is considerably higher than the figure used in government planning, which basically considers only direct economic and not environmental costs. This should have consequences both for the rate of hydropower development and for the pricing of electricity in the long run, and for the choice between hydro- and gas power in future expansion of electricity capacity. We also confront our implicit valuations with environmental cost estimates obtained from other studies of particular rivers in the MP.

2. THE NORWEGIAN MASTER PLAN FOR WATER RESOURCES

Up until around 1980, the process of granting licenses to develop new water courses in Norway was rather arbitrary. Throughout the 1970s, increased environmental concerns made it more important for the Norwegian government to develop those projects with the greatest overall positive net impacts on Norwegian society, where both potential positive economic and negative environmental aspects were included.[1] The MP was designed to rank the remaining hydroelectric projects from such a perspective, and the proposal to carry out such a plan was endorsed by the Norwegian government in 1981.[2] The work was headed by the Ministry of Environment (MOE), with the collaboration of several other ministries, agencies, government research institutes, and local authorities.

The MP, presented in 1984, was based on 285 reports covering 310 watercourses and represented an annual power potential of 41 TWh.[3] Altogether, 542 alternative projects were considered. These were all treated in separate reports, worked out in close collaboration among professional experts, local planners and power companies, various interest groups, and the MOE. In the reports, the predicted impacts of the projects for 16 different attributes were described and evaluated. These were the mean expected hydropower capacity, the regional economic impact, the consideration for mapping and data; and 13 so-called *user interests*: nature conservation, outdoor recreation, wildlife, fish, water supply, preservation of cultural monuments, agriculture and forestry, reindeer herding, water quality, prevention of flooding and erosion, ice formation and water temperature, transport, and climate. For each of the user interests, a score on the scale from -4 to $+4$ was assigned to each project. A score of -4 indicates a very serious negative impact (in principle, a "worst possible" case), and $+4$ a similarly positive impact. Overall, very few of the scores were positive.

The MOE then ranked the projects on the basis of a total evaluation of all 13 user interest scores, project economy,[4] and the regional economy impact score. On this basis, the projects were classified into 16 *priority groups*, with higher-numbered groups considered less suitable for development. The size of a project was not a formal ranking criterion, but some large projects were promoted because of their size.

[1] These initial aims of further hydro development policy were spelled out in [12].

[2] See [11], where this endorsement is expressed. Another purpose of the plan, spelled out in this report, is to determine which water courses are to be used for other purposes than hydroelectric development or protection. The MP is thus neither a pure protection plan nor a development plan, but a more comprehensive "user plan." Here, however, we concentrate on the development aspect of the plan.

[3] The remaining undeveloped hydropower resources were either protected through separate protection plans (17 TWh) or reserved for exploitation to ensure adequate power coverage for the immediate future (11 TWh).

[4] The total development and operating costs per capacity unit.

The MOE ranking is the basis for the present analysis, but we also compare this with the final classification made by the Parliament. This was the result of a process consisting of several steps.[5] Projects were reclassified according to the results of hearing rounds with sector and regional interests. Finally, the plan was treated in the Parliament. This final ranking thus can be taken to summarize the preferences of "political Norway," over the projects in the MP.

The professional work behind the MP, regarding the description and valuation of user interest impacts, was thorough and generally of a high quality and comprised probably the largest single research project carried out by the public sector in Norway, with total expenses in the order of 100 million Norwegian Kroner (NOK) (about 15 million USD). In addition, great administrative resources were spent by ministries, agencies, local administrations, and sector interest organizations. On the whole, we believe it is difficult to find examples, from any country, of national resources that have been scrutinized more carefully, from both a scientific and a public management perspective.

The MP was designed and carried out almost totally in the absence of economic modeling or advice from economists. The decision makers were neither made explicitly aware that their ranking decisions would carry with them an implicit valuation of the user interest variables. In fact, the point of departure of the MOE was that monetary valuations of user interests could not be made, only qualitative valuations.[6]

It is then natural to ask whether the final ranking corresponds to some basic and underlying preferences of government decision makers. This question can be addressed at two interrelated levels. First, are the derived implicit valuations attached to the user interests in accordance with underlying government preferences? Second, have projects been ranked consistently? These topics are discussed further below.

3. A MODEL FOR THE RETROSPECTIVE ANALYSIS OF THE MP PROCESS

In this section we study how the variables describing attributes of individual projects have influenced the ranking of projects in the 16 priority groups (Pr). The relevant explanatory variables are construction and operating (in the following "economic") costs per unit of expected output (C/P), the scores tied to the 13 user interests (S_1–S_{13}), and the regional economics index (R). The ranking is

[5] For a further discussion see [9].

[6] Note, however, that one independent attempt to determine user interest costs, [14], was carried out in 1984–1985 (after the MOE ranking procedure but before the decisions on the MP in the Parliament). They used a multicriteria analysis where a consistent set of potential decision makers' preferences for the various environmental impacts of hydropower development were elicited through an interactive computer program. The ranking of projects derived from these estimated user interest costs differed substantially from that of the MP. Their study was made available to the MOE, having only a minor impact on the final ranking of projects. Two other studies by economists, [1] and [5], were carried out to assess the total excess construction costs and total user benefits, respectively (the latter through a national contingent valuation study), of developing projects in the order of the MP as opposed to in order of increasing construction costs alone. These studies concluded that the MP as a whole was socially preferable to a ranking in the order of construction costs, but did not consider the issue of optimal or consistent project ranking addressed here.

viewed as resulting from a systematic consideration of S_1–S_{13}, R, and possibly project size, P, against C/P, expressed in øre per kWh of expected discounted production.[7] We define the decision makers' total implicit costs (TC) per (discounted future expected) output unit of electric energy by

$$\mathrm{TC}/P = C/P + E/P + q_P(P) + q_R(R). \tag{1}$$

Here E is total implicit "environmental costs" (related to the user interests S_1–S_{13}), while q_P and q_R are implicit unit valuations of project size and of the regional economic indexes, respectively. The priority of an arbitrary project i can then be viewed as resulting from a consideration of TC/P and possibly other factors:

$$\begin{aligned}\Pr(i) &= h((\mathrm{TC}/P)(i), e(i)) \\ &= f(P(i), (C/P)(i), R(i), S_1(i), \ldots, S_{13}(i)) + e(i).\end{aligned} \tag{2}$$

The $e(i)$ here represent factors affecting project priority which cannot be explained by our model. They are considered additive and purely random. We specify (2) in a form suitable for estimation, in the simple way,

$$\begin{aligned}\Pr(i) &= b_0 + b_P P(i) + b_C (C/P)(i) \\ &\quad + \sum_{j=1}^{4} b_{Rj} D_{Rj}(i) + \sum_{k=1}^{13} \sum_{j=1}^{4} b_{kj} D_{kj}(i) + e(i).\end{aligned} \tag{3}$$

Here D_{Rj} and D_{kj} are binary variables, respectively related to the regional economics index and to the scores S_k given to the 13 user interests ($k = 1, \ldots, 13$) for each of the projects. $D_{Rj}(i) = 1$ if and only if $R(i) = j$ and is zero otherwise. Similarly, for the user interests, $D_{kj}(i) = 1$ if and only if $S_k(i) = j$, $D_{kj}(i) = -1$ if and only if $S_k(i) = -j$, and is zero otherwise.[8] The priority variable Pr in (3) represents ordinal ranking numbers. We therefore estimate its parameters with ordinal logistic regression analysis (using the SAS program). This amounts to assuming that there is an unobservable continuous construct underlying the ordinal measure and that the explanatory variables actually determine the probability that a project will be assigned to a specific priority group. We also perform a secondary analysis, however, where we interpret (3) as an OLS regression model. This implies the stronger assumption that the ranking numbers are measured on a linear interval scale. Reference [4] conjectures that it is safe to use OLS when the number of ordered categories increases beyond four levels. When in doubt, both models should be used. If the two models give the same substantive results, the simpler OLS regression model is also an acceptable approach.

Our formulation (3) implies the following more specific assumptions:

(a) Priority is taken to be affected linearly and additively by all the variables included. This implies an assumption of no "synergy effects" between the explana-

[7] We are here assuming a project lifetime of 40 years and a real interest rate of 7%, implying a "discounted lifetime factor" of 13.3. One-hundred øre is 1 NOK or about 15 cents.

[8] This represents a symmetry assumption: the negative effect on priority of a given negative score is taken to equal the positive effect of the same positive score. This was necessary in order to handle the small number of positive scores occurring in our data, and turns out to have very little impact on other results.

tory variables, in particular the user interests. We did attempt to estimate alternative model formulations permitting such effects, without obtaining better fits.[9]

(b) An increase of $-b_{kj}/b_C$ in economic costs per output unit gives the same effect on priority as a change in the user interest k score from 0 to $-j$ (where typically the b_{kj} will be negative). This permits a very simple interpretation of the estimated ratios $-b_{Rj}/b_C$, as the decision makers' *implicit willingness to pay* to avoid a user interest conflict of $-j$ for user interest k.[10] The same principle applies to $-b_{Rj}/b_C$, which express the valuation per output unit, attached to a regional economics score of j, for a given project. Note the quite restrictive assumption that for all projects with a given score for a given user interest or regional economy, the implicit costs per output unit is the same.

(c) Our formulation implies that the *absolute* valuations attached to user interest and regional economics scores are scaled by the size of the projects (since, e.g., the ratios $-b_{kj}/b_C$ express valuations *per unit of output*). Among several alternatives this formulation clearly gave the best fit.[11] Apparently, the participating scientists and officials have systematically assessed user interest scores relative to project size and used them accordingly in the ranking process.

In preliminary estimations we found no effect on priority of the score attached to water pollution, prevention of flooding and erosion, ice formation and water temperature, transportation, and climate. The sample applies to the scores of -1 and -2 for some of the remaining user interests. These were left out of the estimations to be presented in the following section.[12]

4. RESULTS FROM THE STUDY

Equation (3) is estimated by ordinal logistic regression analysis, where the 542 projects are treated as observations. As expected, $b_C > 0$, and $b_{R2} < b_{R1} < 0$, i.e., a lower economic cost and a greater favorable regional economic impact places a project in a lower-numbered regional priority group. The estimated b_{kj}-coefficients are all negative. This implies that for all eight included user interest variables, all scores from -1 to -4 are seen to have negative impacts on project priority, i.e., lead to projects being ranked in higher categories. This tendency is generally weak for the scores of -1 and -2, stronger for -3, and particularly strong for -4. The coefficients of the model are significantly different from zero at

[9] These alternative formulations included also products of pairs of key user interest variables on the right-hand side. Almost none of these were significant, and the fit measured by the multiple R^2 in an ordinary least-squares regression model was only marginally affected.

[10] Note that such a simple interpretation of coefficients would not have been possible with a nonlinear model, thus increasing the attractiveness of our linearity assumption.

[11] An alternative would be to include C instead of C/P in (3). $-b_{kj}/b_C$ should then rather be interpreted as an *absolute* cost attached to the user interest score $-j$ for a project; i.e., the implicit willingness to pay to avoid a conflict of $-j$ would be the same for all projects, irrespective of size. Such a formulation was attempted, but had almost no explanatory power.

[12] Apparently, these variables had no systematic effect on the rankings; excluding them affects the other coefficients only very marginally and yields a model that is easier to communicate and interpret. Moreover, discussions with participants in the ranking process reveal that in particular the -1 scores had no impact at all on the rankings. It is therefore likely that the simpler model is a truer representation of the actual decision process.