Chapter 2
The Dönje Hydropower Scenario

In this chapter we present the cost-benefit analysis of the Dönje hydropower plant re-regulation. In Sect. 2.1 the theoretical cost-benefit rule underlying the empirical study is briefly discussed. It is seemingly simple but is derived in [1] for a quite complex open economy setting. We then go on to the empirical study. In Sects. 2.2 and 2.3 the major benefits of the re-regulation are presented. These are environmental such as more salmon in the river, and hence improved fishery, improved aesthetical values, improved canoing and other such leisure activities. A web-based questionnaire was used to assess the willingness-to-pay (WTP) for these benefits. The valuation question is novel in the sense that it introduces intervals (upper and lower bounds for WTP) that are selected by the respondent. The chapter then goes on in Sects. 2.4 and 2.5 to estimate the costs of the proposal. These are mainly the loss of profits by the hydropower company and externalities of coal-fired replacement power. The intricate question how to discount benefits and costs is addressed in Sect. 2.6. The results are summed up and point estimates are presented in Sect. 2.7. A sensitivity analysis of the result of the cost-benefit analysis ends the chapter.

2.1 The Basic Cost-Benefit Rule

In this section we discuss how to design a cost-benefit rule to be used to assess the re-regulations, i.e. changes in water use, suggested by the two considered scenarios. We present a simple general equilibrium cost-benefit rule for a tax-distorted economy. The small or marginal project under consideration diverts water from electricity production to more environmentally friendly uses. The items in the associated cost-benefit rule are briefly discussed here. More detailed derivations are available in [1]; a sketch of the general principles can be found in Appendix A. It should be added that our evaluation is *ex ante*, i.e. we consider re-regulations that have not yet occurred;

Thanks to Springer for allowing us to draw on [1].

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for a recent *ex post* analysis of dam relicensing in Michigan the reader is referred to [2].

The special feature of the project under consideration is that it involves a private, reasonably profit-maximizing multinational firm in part owned by foreigners. At first glance, the scenario seems inexpensive to Swedes, because a large fraction of the shareholders are not part of the Swedish society. A significant fraction of the loss of profit is borne by individuals outside the conventional definition of a society, unless Swedes have some altruistic reasons to include the well-being of these foreigners in their utility functions. However, if we respect property rights, there is no obvious way to force the firm to deviate from its profit maximizing use of its water use rights. Therefore, the way to proceed is to provide the firm with an incentive to use less water for electricity generation. In effect, this is equivalent to buying back some of the company's water use rights or to in some other way "bribe" the company to change its level of production.[1] The approach means that the assumed *counterfactual* or *baseline* is "doing nothing" or "business as usual". Thus in the absence of the considered project the current regulation is assumed to remain unchanged over the considered time horizon.

In Appendix A we present a simple general equilibrium model of a small open economy. Cost-benefit rules are generated by marginally changing a parameter and tracing the changes from one general equilibrium to another. The parameter used here is interpreted as a contract according to which the firm receives a sum of money in return for a reduction in its electricity generation at the Dönje plant. The resulting societal cost-benefit rules for a *small* change, which is derived in detail for a small open economy in [1], can be stated as follows

$$\Delta W^M = \sum_h WTP_h \cdot \Delta E + \Delta\pi - \sum_h WTA_h \cdot \Delta EM + \Delta T^d \qquad (2.1)$$

where ΔW^M denotes the change in societal welfare converted to monetary units, WTP_h is the present value willingness-to-pay (WTP) of individual h ($h = 1, \ldots, H$) for environmental gains, denoted ΔE, associated with the project, $\Delta\pi$ is the present value loss of before-tax profits of the hydropower firm, WTA_h (≥ 0) is the smallest compensation needed to willingly accept increased emissions from replacement power, ΔEM (≥ 0) is the magnitude of harmful emissions emitted by replacement power, and ΔT^d (≤ 0) is a term reflecting the distortion in the electricity market (difference between consumer and producer prices) and some other minor items as explained in [1]. We define a small or marginal project as a parametric change that can be captured reasonably well by a linear approximation (in our case of a social welfare function). This means that second order and higher order terms, denoted R in Eq. (A.4) in Appendix A, are assumed to be approximately equal to zero.

[1] From a legal point of view the Swedish water use rights concept is quite complex. In this Brief we will speak of buying/selling such rights. Thereby we simply mean a contract between two parties stating the present value sum of money paid in exchange for a specified change in water use.

The term ΔE covers two distinct environmental consequences associated with diverting water from electricity generation. The first consequence relates to a possibly smoother downstream water flow. There are stochastic short-run variations in supply (a nuclear power plant, for example, might suddenly shut down) and demand (due to a sudden change in temperature, for example) and also forecast errors by producers. Such variations are largely handled by hydropower in the Nordic countries; the reader is referred to [3, 4] for detailed analyses of the properties of different regulating services. However, the other side of the coin is that sudden changes in the water flow may cause damages to the river basin and sometimes creates a moon-like landscape. If the considered change at Dönje causes a less volatile or more smooth water flow, there is a benefit. However, it was deemed likely that the impact is so marginal that the associated willingness-to-pay is set equal to zero.

The second consequence relates to the main purpose of the considered project. This purpose is to improve the recreational and other values of the basin downstream the Dönje power plant. The associated willingness to pay (WTP) for these values is captured by the term WTP_h in Eq. (2.1). Since Fortum has acquired the water use rights it is legitimate to use a WTP concept rather than a willingness to accept compensation (WTA) concept.[2] In other words, the local residents must pay to obtain an improved environmental quality.

In the empirical study it is assumed that $WTP_i \geq 0$, where a subscript i refers to an individual living in the municipality of Bollnäs.[3] Since the scenario analyzed in this study is small we set $WTP_j = 0$ for all individuals j living outside the considered municipality. Thus in Eq. (2.1) $\Sigma_h WTP_h \cdot \Delta E$ is simply equal to the sum of $WTP_i \cdot \Delta E$ for all i, i.e. all residents of the municipality of Bollnäs.

The second term in Eq. (2.1) captures the loss of present value pre-tax profits of the hydropower plant as water is diverted from electricity generation. The single period loss is $\Delta\pi_t = (p_t^s - MC_t) \cdot \Delta x^s$, where the subscript t refers to period t, p_t^s is the spot price at time t,[4] MC_t is the marginal cost, and $\Delta x^s < 0$ is the constant reduction in electricity generation at the plant. An illustration of the profit loss argument is found in Fig. 2.1 where the (highly simplified) "supply ladder" shifts to the left due to the considered project; it is assumed that the annual loss of electricity is equal to 3.7 GWh just as in our scenario. Cheap hydropower is replaced by electricity generated by a marginal supplier. Hydropower, wind power, and nuclear power plants have low but different marginal costs and are to the left on the ladder while fossil-fueled plants (coal-fired, oil-fired and gas-fired) have high marginal costs and hence are to the right of the ladder. The spot price is "determined" by the marginal supplier.

The principal cost for the project is the difference in costs between the two power sources; the reader might note that the difference between the two dark staples is

[2] For discussion of these concepts the reader is referred to, for example, [5] or [6].

[3] In order to simplify notation, people living in nearby communities are included in the municipality of Bollnäs.

[4] The firm might also earn a revenue from providing balance services to the power grid but as explained above these services are probably not affected by the considered marginal shift in production.

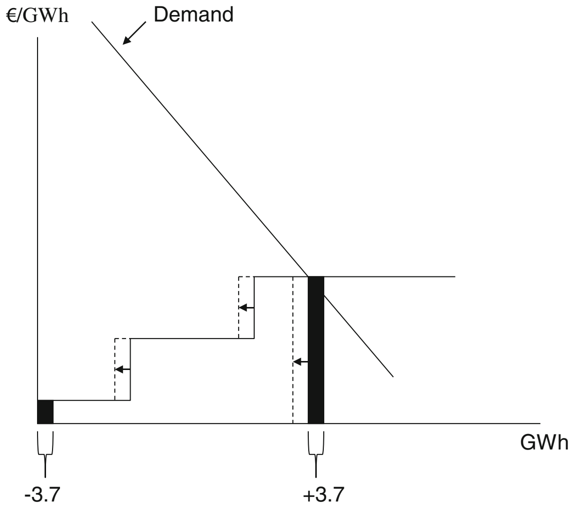

Fig. 2.1 A simplified spot market for electricity. *Source* own work

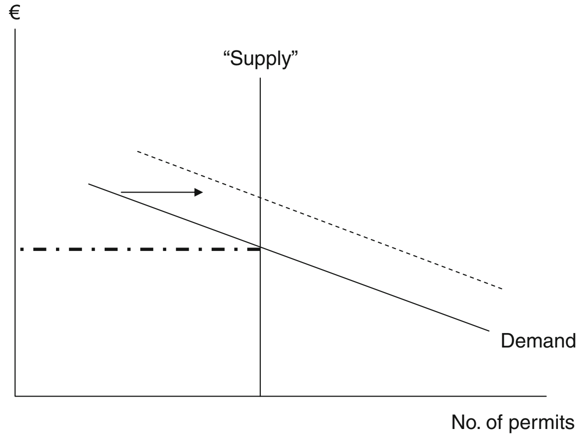

Fig. 2.2 A simple illustration of a permit market. *Source* own work

equal to the annual loss of profits for the Dönje plant if its annual production decreases by 3.7 GWh. In order to arrive at the present value term $\Delta\pi$ in Eq. (2.1) forecasts for p_t^s and MC_t are needed as well as a social discount rate.

In our base scenario a reduction in the electricity generation at Dönje is assumed to be covered by increased production by (foreign) fossil-fired power plants. This will be further clarified when we describe the operation of the Nord Pool spot market. These fossil-fired plants cause emissions of climate gases. However, if there are permit markets net emissions will remain unchanged, as is illustrated in Fig. 2.2. A fossil-fired plant that increases its electricity generation must acquire permits which means that through a price adjustment some other producer will be induced to reduce its emissions, i.e. to sell some of it permits. However, not all climate gases are covered by the European trading scheme. Moreover, emissions of other gases, such as sulphur and nitrogen, might increase as Sweden imports more fossil-based electricity.[5]

A conventional cost-benefit analysis deals with monetary welfare consequences at the national level. The key question is if this implies that consequences of a project occurring outside the borders of the country should be ignored. A standard cost-benefit analysis, just like conventional welfare theory, relies on the concept of consumer sovereignty, so that individual preferences should be respected. Therefore, if Swedes are "nationalistic" egoists in the sense that they care only about damage within the borders of the country, the cost-benefit analysis should ignore any damage caused abroad by replacement power. On the other hand, if Swedes care about the impact of their actions irrespective of where the damage occurs, a cost-benefit analysis should respect this fact. In the base case we will assume that the representative Swede is an altruist in the sense that he or she cares about any damage Swedish actions caused abroad.[6] The term $\sum_h WTA_h \cdot \Delta EM$ is supposed to cover the minimum aggregate (national) compensation needed for accepting the total of all extra emissions, regardless of whether they cause damage domestically or abroad.[7] It is important to realize that we here consider a WTA concept (preceded by a minus sign) rather than a WTP one. The reason is that an increase in emissions causes a loss of welfare.

An alternative to the national level approach used here would be to use a European Union or even a global perspective where the costs to and benefits for the Union or the globe are estimated but such an approach seems to be at odds with the conventional definition of a social cost-benefit analysis which loosely restricts it to dealing with residents of a nation or country. However, there are exceptions, for example, the famous "Stern Review" in [10] of the global costs of climate change and [11] who discuss evaluations at the European Union level. It is also important to stress that this Brief throughout considers small or marginal projects. For recent general equilibrium evaluations of large or non-marginal projects, the reader is referred to [12–14].

Finally, there is the tax term in Eq. (2.1). As is shown in [1] this term is basically the same general equilibrium tax rule as the one stated in Eq. (15) in [15]. In particular, in the present case it reflects the difference between the consumer and producer prices of electricity (and some other, but small, items that are ignored in this Brief). If aggregate demand for electricity is left unchanged by the considered small parametric change, then $\Delta T^d = 0$. This is the assumption maintained in the base case of the study; recall that the loss at Dönje is assumed to be covered by increased production at another power station. On the other hand if the project causes a small price increase some

[5] The power plant acquiring permits must crowd out some other producer demanding permits. From a general equilibrium perspective it is more or less impossible to estimate the net impact on emissions. The outcome depends, for example, on whether a steel producer or a oil refinery is crowded out. Moreover a relocation of plants from the Union to other parts of the world might be "triggered" by a new project requiring permits.

[6] The reader is referred to [7–9] for detailed discussion of different altruism-concepts.

[7] Even a hydropower plant causes emissions in a life cycle perspective. However, since we only consider a marginal change in water use we assume that there is a net increase in emissions if we shift to fossil-fired plants.

consumers might reduce their demand for electricity. In this case $\Delta T^d < 0$ while $\Delta EM = 0$ since, by assumption $\Delta x^d = \Delta x^s$, i.e. no replacement power is needed. This case is briefly considered in the sensitivity analysis.[8]

The cost-benefit rule stated in Eq. (2.1) is remarkably simple. Still and as developed in [1] it resembles the one obtained using a quite complex and tax-distorted general equilibrium model of a small open economy. The framework integrates several key issues, including, but not limited to:

- a contract between the hydropower plant and another party (local residents) generating the general equilibrium cost-benefit rule, which is a cornerstone of our referendum-style Contingent Valuation study
- the tax system in the status quo
- partial foreign ownership of the hydropower company
- trade in electricity, renewable energy (electricity) certificates and carbon emission permits
- externalities of replacement power (generated in other countries)
- value of loss of regulating (balancing power) and other system services
- transmission of electricity modeled as provided by natural monopolies
- downstream hydrological externalities
- environmental benefits (aesthetic and otherwise).

A rather unique aspect of our empirical analysis is that we have assessed the environmental impacts from the perturbation by an actual experiment at the plant. Thus, the perturbations have been implemented in a "test-run" and the ecological consequences thus monitored "live" on-site. We proceed by providing a brief description of the scenarios.

2.2 The Impact of Changed Water Flow at the Hydropower Plant

The natural science team of the research project carried out detailed experiments at the power plant, in order to assess how a changed flow would affect fish ecology. Their study target, Klumpströmmen, is unusual compared to many other rivers and river sections in Sweden. For example, it has not been cleaned for timber floating. Therefore the riverbed is more heterogenous than the average river, even when compared to unregulated rivers. This aspect has a positive influence on potential biological productivity. In addition, Klumpströmmen is an outlet stream and this contributes to productivity, both concerning fish- and benthic fauna. However, the outlet effect is not unique to Klumpströmmen. In fact, many bypass channels are close to dams, which mean that outlet effects should be common in these types of systems.

[8] The reader is referred to [1] for a discussion of how this approach is related to the concepts of the Marginal Cost of Public Funds (MCPF) and the Marginal Excess Burden of Taxes (MEB).

Our scenarios are typical constant flow regimes, with a low winter flow and a higher summer flow. Alternatively, we could have suggested a variable flow to mimic a natural flow regime. However, the power station in Dönje has a maximum capacity which is exceeded at high flows. Therefore, the flow in Klumpströmmen is expected to become variable even in the absence of a legislated two-level flow. The most important aspect that makes our scenario "tick" is that Klumpströmmen is a natural or bypass channel. Before the hydroplant was constructed, Klumpströmmen had about 25 % of the total flow; during extreme highflows excess water can be spilled into the main channel to protect the smaller Klumpströmmen from severe disturbance during extreme high flow events.

Six flow regimes ranging from the present minimum legislated winter flow of $0.25\,m^3s^{-1}$ to pristine low summer flows of $41\,m^3s^{-1}$ were evaluated at the regulated, but uniquely pristine stretch, Klumpströmmen. These scenarios were generated "live", by asking the power company to release certain amounts of water during prescribed periods of time. Thus, in June 2008 (when the minimum required flow is $10\,m^3s^{-1}$), 21 and $41\,m^3s^{-1}$ were released from the plant. In May 2007, during the minimum legislated winter flow, the team looked at flows lower than $10\,m^3s^{-1}$, but higher than $0.25\,m^3s^{-1}$.

Compared to the minimum winter flow, with no suitable habitats for grayling and brown trout, the area of suitable spawning and juvenile habitats at $3\,m^3s^{-1}$ were estimated to 3 ha, and 0.5 for adults. At the present legislated minimum summer flow of $10\,m^3s^{-1}$, the suitable habitats covered an area of about 3 ha for juveniles and 4 ha for adults. At higher flows, these areas increased proportionally less than the corresponding increase in the flow ($21\,m^3s^{-1}$; juveniles 4 ha, adults 5–6 ha and $41\,m^3s^{-1}$; juveniles 6 ha, adults 8–9 ha).

Snorkeling in the river section indicated low relative fish densities, averaging 0.39 grayling per $100\,m^2$, while no brown trout was observed. By electro-fishing, an average of 0.14 brown trout per $100\,m^2$ was estimated, which in relation to reference data indicated a very low density. Based on the collected information, the current flow regulations in the section seem to impair fish populations. With environmentally adapted flows implying c. 1.5 month earlier start and ending of minimum summer flow, and increasing the minimum winter flow from 0.25 to $3\,m^3s^{-1}$, the salmonoid density was predicted to increase by a factor of 3–6 compared to that estimated in the field, see [16, 17]. These predictions, combined with other information about the possible impact of the scenarios, were included in the contingent valuation study, to which we now turn.

2.3 Contingent Valuation Study of Improved Downstream River Basin

The contingent valuation study targeted respondents in the Bollnäs municipality (but the survey also gave some information about WTP in neighboring municipalities). It was preceded by the focus groups analysis described below and the on-site ecological assessment described above. These two studies were basic ingredients in the scenario development. An important step in the development of a survey is to conduct focus groups to test how a general audience interprets the survey (subsequent steps include survey revisions, a pilot study, and a final study. This last step was omitted here, because the web-panel was essentially exhaustive in the Bollnäs area and we did not have resources to undertake additional in-person or telephone interviews). Specifically, our focus groups were designed to ensure, among other things, that the proposed environmental changes and the hypothetical valuation scenario described in the survey were understood by respondents. The reader is referred to [1] for a detailed presentation of the results of the focus-groups study.

Given the insights obtained from the focus-groups, we then proceeded to revise our survey instrument. A web-based sample was obtained providing 136 completed surveys for the Bollnäs municipality, and 200 completed surveys in total. The 64 questionnaires (200−136) not from the Bollnäs municipality came from households in neighboring municipalities (5 cases had invalid zip codes and were deleted from the analysis of residence).

We then undertook a straightforward representativity analysis of the sample. This analysis shows that there are only small differences between our sample and the population of Bollnäs. An interesting fact is that we had a slight underrepresentation of young households and a slight overrepresentation of old, which might not be expected in a web-survey.

The WTP-question was formulated as a referendum in the Bollnäs municipality. This follows a long-standing tradition of local referenda in some countries/states (e.g. Switzerland/California) in general and on water issues in particular. For example, the *Wyoming Preserve Minimum Instream Water Flows Initiative*, May 23, 1982 in Wyoming, USA, mandated leaving a certain level of water in streams so that natural fisheries could thrive. The initiative was set for the 1986 ballot, but did not make it.[9]

In the present study the question was formulated in the following way:

WTP-question introduction *It has become more common in Sweden that those who are affected by local environmental issues are able to vote in local referendums. The following proposal can be viewed as such a local referendum. It is thought to be held among inhabitants of Bollnäs municipality. The purpose of this question is to shed some light on how the average citizen of Bollnäs values a potential change of the water flow in the Bollnäs streams. The change will improve fishing conditions, water ecology and landscape aesthetics. At present, the water rights are owned by the Fortum company. This means that Fortum has the right to produce electricity at the Dönje plant. Suppose that the only possible way to increase the water flow in the Bollnäs streams is to buy back those water rights, by means of a joint action among Bollnäs citizens.*

[9] It was argued that the Wyoming State Legislature in 1985 accomplished substantially the same objectives. Source http://ballotpedia.org/wiki/index.php/Wyoming_Preserve_Minimum_Instream_Flows_Initiative_(1986).

We then described the winter-season proposal.

Proposal to change of the winter season water flow in the Bollnäs streams. *The* ***Proposal*** *entails an increase of the winter season water flow from 0.25 to 3* $\mathrm{m^3s^{-1}}$. *There will be no change in the summer season water flow. This means that the water flow will increase from the power station to Varpen (note: this was described in a map not included here) The proposal is depicted in a series of pictures in the sequel. The total costs for the* ***Proposal*** *is not known with certainty at the present time. Suppose that the referendum is held when the cost has become known. If a majority supports the proposal, it will be undertaken. A "yes" entails each household paying a given sum over a period of 5 years.*

A series of pictures were introduced in order to depict the winter scenario, i.e. SCENARIO 1. For SCENARIO 2, a picture was added showing the summer season change. These and the detailed written information provided about the impacts of the proposed changes can be found in [1].

The next question included an opt-out possibility, i.e. a zero WTP possibility. Those who rejected this option could then state their WTP. If an individual was not able to state WTP as a point he was asked to state it as a freely chosen interval. This last feature is unique, to the best of our knowledge, and opens up for challenging theoretical and econometric exercises.

Turning to the results, it is of interest to consider the "size of the market". Because the scenario entails payment responsibility only for those living in the Bollnäs municipality, we focus on these respondents in the sequel. Around 62 % reports $WTP > 0$ and 38 % reports $WTP = 0$. Thus there is a majority in favor of the project. Further results are summed up in Table 2.1.

The table makes it plain that we do have a sparsity of data, and, again, our analysis here is only to illustrate how to undertake a modern cost-benefit analysis of water use conflicts. In order to obtain average WTP, we simply add the proportion of zero WTP in the data, i.e. those respondents who claim not to be "in-the-market". In so doing, we need to handle the 6 respondents who reported an interval (0,upper). We interpret them to be in the market.

The figure that we use in the empirical CBA is taken from Table 2.1 by including the zero answers. It is calculated as $\frac{36}{135} \times 482,25 + \frac{47}{135} \times 495,08 \approx 300$, where 495.08 is the average of the mid-points. It should be noted that there was no difference in average WTP between SCENARIO 1 and 2. Our hypothesis is that the reason lies

Table 2.1 Descriptives of WTP, conditional on $WTP > 0$

WTP	n	Unique	Mean	0.50	0.75	0.90	0.95
Lower	47	13	214.3	100	100	540	1000
Point	36	13	482.2	250	500	1000	1375
Upper	47	19	775.9	500.0	1100.0	1700.0	2350

Source own work

in the fact that the difference between the status quo and the scenario, i.e. from 10 to 20 $m^3 s^{-1}$ in the summer season, is quite small and hard to recognize.

In [1] we present estimates (and computer programs) based on the Jammalamadaka estimator, a Weibull distribution, and the Belyaev-Kriström estimator. These estimates are 286, 258, and 285, respectively, and are hence quite close to the estimate used in the CBA, although we must emphasize that the number of observations is very small. It is noted that [18] report very similar estimates using different estimators but the same data set, their means ranging from 258 to 334, depending on the specific assumptions made. Finally, to repeat, for ease of replication we use the rounded number 300 as our estimate of the average annual 5-year WTP for the project's benefits in the empirical CBA.

2.4 The Cost of Electricity Foregone

The primary cost of the project is the value of the hydroelectricity foregone when water is diverted to other uses. The physical loss (in SCENARIO 1) was estimated to 3.7 GWh per year[10]; see Sect. 3.3 or [1] for the simple engineering formula used for the estimation.

A central part of the CBA is to construct a trajectory for the price of electricity. The point of departure is the spot price at the Nordic (Denmark, Finland, Norway and Sweden) spot market Nord Pool. Typically the marginal supplier on the spot market is a fossil-fired plant (i.e. would be on the final step of the highly simplified supply ladder in Fig. 2.1). This fact means that the spot price will reflect the price of carbon emission permits. Recall that fossil-fired plants must acquire a permit for each ton of carbon dioxide they emit, which implies that their marginal costs reflects the marginal cost of permits. In recent years the price of carbon permits at the Nord Pool market has typically varied between EUR 15 to EUR 20 per EUA, with the holder of one EUA (European Union Allowance) being entitled to emit one ton of carbon dioxide or carbon equivalent greenhouse gas.[11]

In Fig. 2.3 we show how the Nord Pool spot price (system price[12]) for electricity has fluctuated from 1996 to 2010 (inclusive). The "spikes" in 2003 and 2006 are due to dry conditions, leading to a low supply of hydroelectricity, while the spikes in early to late 2010 were due to extremely cold periods and transmission problems. The figure includes the linear trend of the spot price.

There is trade between the Nordic countries and Estonia, Germany, the Netherlands, Poland and Russia. Hence the price on the Nord Pool is not independent of what

[10] In SCENARIO 2 the annual loss is estimated to 14.3 GWh.

[11] See the PDF file entitled "Marknadspriser" at www.svenskenergi.se.

[12] There are sometimes bottlenecks in the transmission of electricity implying that the Swedish price deviates from the system price. Here we ignore such deviations since we focus on long run issues. Historical spot prices are available at Nord Pool's home page: http://www.nordpool.com/asa/. Since inflation has been very low during the considered period we report the spot price in current terms.

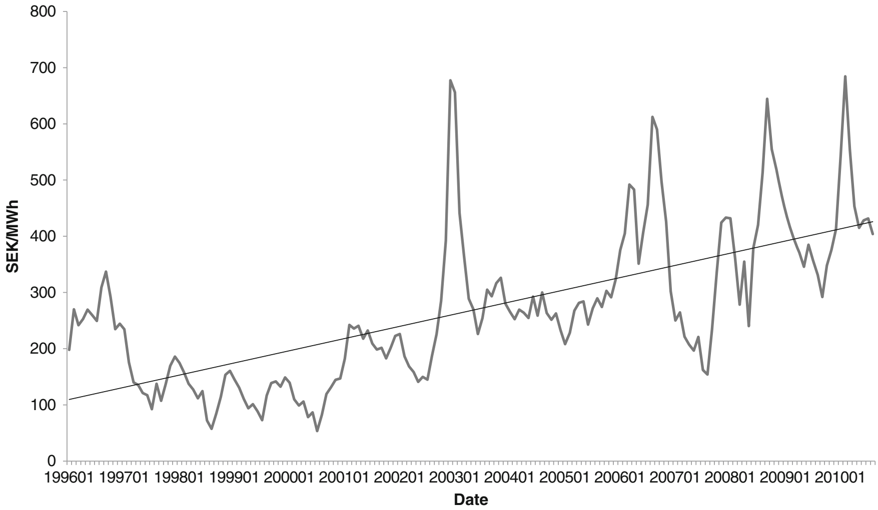

Fig. 2.3 Average monthly spot prices (system price) in SEK/MWh 1996–2010 and the linear price trend on the Nord Pool market. *Source* own work based on data from Nord Pool Market

happens in the electricity markets in the surrounding area.[13] For example, in the dry years of 2003 and 2006, the Nordic countries did import electricity from Germany, Poland and Russia. In particular, the spot market of the Leipzig based European Energy Exchange, EEX, is of interest in the present context. This is because from the point of view of Nordic hydroelectricity producers it seems to be ideal to have unlimited transmission capacity to Germany since the EEX spot price typically is higher than the Nordic one and has a different profile across the day. The German merit order curve looks similar to the Nordic one but there are also important differences. In contrast to the Nordic system, Germany has little hydroelectricity and a lot of lignite-fired power plants. Germany also has pumped-storage plants for electricity generation during peak hours.[14]

In the CBA two different price trajectories are used. The first price trajectory is a conservative one which is aimed at providing a reasonable *lower bound* for the loss of revenues of the Dönje plant. According to this scenario, the price received by Dönje "today" is equal to our estimate of Nord Pool's (system) spot price for an average or "normal" year with respect to precipitation. This price, assumed to be constant over time, is set to SEK[15] 350/MWh (about EUR 35/MWh) and corresponds roughly to the average spot price during the period 2003–2010; the average is SEK 361/MWh.

[13] For a good treatment of European electricity markets the reader is referred to [19].

[14] A pumped-storage plant (typically) works as follows. At night, when electric demand is low, the plant's reversible turbines pump water (uphill) to a reservoir. During the day, when electric demand is high, the reservoir releases water through the turbines.

[15] A Swedish krona (SEK) is here assumed to be worth about EUR 0.1 in the long run, i.e. EUR 1 is equal to SEK 10.

This forecast is consistent with the idea of mean-reversion, which is the tendency for a stochastic process to return over time to a long-run average value. The reader is referred to [20] for further discussion of the concept of mean-reversion in the context of electricity markets.

The second price trajectory is supposed to provide a reasonable *upper bound* for the loss of revenues for the Dönje plant. The best scenario of Swedish hydropower proponents is arguably a "merger" of Nord Pool and the German EEX market. In this scenario Swedish hydropower is sold at the German peak load price from 2030 and on. We assume that the initial average German peak load price is SEK 700/MWh (about EUR 70/MWh), which corresponds to the average price during the period 2005–2008, and that the average price stays constant at this level. As in the first scenario, the initial price received by the Dönje plant is assumed to be equal the "normal" annual spot price on the Nord Pool market, i.e. SEK 350/MWh, and then linearly approaches the German peak load price in such a way that they become equal in 2030. This corresponds to an annual real price increase of 5 % during the period 2010–2030 so that the real spot price reaches SEK 700/MWh in 2030 and then stays constant.

It might be argued that the first price trajectory represents "business as usual" in the sense that there are no major changes in the market. The second trajectory accounts for a possible major long-run structural change in market conditions. In our cost-benefit analyses we will draw on point estimates of the different items. With respect to the price trajectories we assume arbitrarily that the spot price at each point in time is an i.i.d uniform random variable over the interval (p_t^{slb}, p_t^{sub}), where p_t^{slb} (p_t^{sub}) denotes the lower bound (upper bound) estimate of the spot price at time t. This is the simplest possible continuous random process and means that the point estimate of the spot price at time t is equal to $(p_t^{slb} + p_t^{sub})/2$. This means that the initial assumed spot price is SEK 350/MWh and that the price increases linearly to reach SEK 630/MWh after 20 years and then stays constant in real terms. This trajectory yields the same present value revenue loss as if we use what might be termed a *certainty equivalent price* of just above SEK 480/MWh if the discount rate is 3 %,[16] i.e. the same present value revenue loss as if the price is constant over time and equal to SEK 480/MWh. As a comparison it might be noted that the Swedish Energy Agency, which is a government agency for national energy policy issues, in a recent long-run forecast (see [21]), estimates the spot price (or rather Swedish system price) to be SEK 500–520/MWh over the next 20 years in 2010 prices. In contrast to one of our price trajectories this last forecast seemingly ignores any major changes in international transmission lines.

Then we are equipped with the spot price p_t^s and the annual loss of electricity Δx^s in the annual profits loss expression $\Delta\pi_t = (p_t^s - MC_t) \cdot \Delta x^s$. The marginal cost MC_t for Swedish hydropower plants is considered to be low. In fact, according to several studies the variable costs of *new* plants are virtually zero. Here it is arbitrarily set equal to SEK 30/MWh for the existing plant and to zero once it is replaced by new equipment.

[16] Unless otherwise stated we assume that society is risk neutral.

2.5 Pollution Externalities of Replacement Power

If the electricity foregone at Dönje is replaced it is most likely replaced by Danish coal-based electricity. This is often the marginal source on the Nord Pool spot price market (although supply and demand for electricity shifts over the hour, the day, the season, and so on). It is well-known that coal-fired plants cause emissions that might hurt the health of human beings as well as affect the environment (fauna and flora).

In order to put a price tag on these externalities we will use a simple approach. The estimate is based on EcoSenseLE V1.3, a web-based tool for estimating externality costs within the EU.[17] It provides a rough estimate of the shadow prices of increased morbidity and mortality, damage on crops and materials, and climate gases that are not covered by the European carbon trading system. We include emissions of NO_x, SO_2, particulates, NMVOC, CH_4, and N_2O in the way detailed in [1]. The annual cost is estimated to be EUR 3 039 per GWh (about SEK 30 500). This estimate is assumed to reflect the annual compensation Swedes in total request in order to be indifferent to the emissions per GWh caused by replacement power. Thus in the base case we assume that Swedes are altruists in the sense that they care about damage inflicted on others even if these people, animals, plants, and so on, live in foreign countries.

If an emission is subject to an emission tax the externality is partly or wholly internalized. Since EcoSenseLE does not account for this phenomenon our approach could be interpreted as equivalent to assuming that Swedes are paternalistic altruists. That is, Swedes care about the "physical" impact of emissions ignoring that externalities might be fully or partially internalized through taxation. Even if we accept the altruism-assumption it is far from obvious whether our approach overestimates or underestimates the true damage. On the one hand, some particulates are not accounted for by the EcoSenseLE V1.3 model. On the other hand, replacement power production crowds out some other activity in the carbon permits market; recall that there is a *fixed* number of permits. In principle one would need a *global* computable general equilibrium model linked to an emissions model to be able to track down the net impact on different emission sources. Unfortunately, no such model is currently available.

2.6 Social Discount Rate

There is a huge literature on how to define and estimate a social discount rate. There is certainly no universal consensus with respect to what a social discount rate reflects, its magnitude or even sign. A good overview of different approaches is found in [22]. We will not attempt to summarize the different approaches and views here. We just note that the UK uses a base rate of 3.5 % (including 1 % reflecting reflecting catastrophe

[17] See http://ecoweb.ier.uni-stuttgart.de:80/ecosense_web/ecosensele_web/frame.php. This web-based tool can be used to replicate the externality costs presented here.

risk), Germany's rate is 3 % while France uses a rate of 4 %; see [23]. Reference [24] argues for a standard benchmark European discount rate of around 3–4 % based on social time preference. The European Commission's Directorate General Regional Policy has suggested a 3.5 % social discount rate for most member states including Sweden when evaluating infrastructure investments; see the Commission's guide to cost-benefit analysis; [23].

Both [22] and the Commission's (2008) CBA guide provide estimates of the Swedish social discount rate. The model used by [22] is the one suggested by [25]:

$$r = (1 + \dot{p})^{1-\alpha}(1 + \dot{y})^{\sigma}(1 + i) - 1 \tag{2.2}$$

where r is the discount rate, $\dot{p}$ is population growth, α gives the weight of population size on social utility, $\dot{y}$ is per capita income growth, σ is the coefficient of relative risk aversion, and i is the pure time preference. According to this model one arrives at discount rates of 2.9–3.4 % if the annual growth rate of per capita income is about 1.8 % as was the case for the period 1970–2008; the higher (lower) rate is obtained if the coefficient of relative risk aversion (σ) is 1.26 (1 as in their base case[18]). It might be noted that the result that $\sigma = 1.26$ was obtained as a best estimate by [26] in a cross-sectional study covering over 50 countries and time periods; the reported estimates are seemingly very robust and vary from roughly 1.2 to 1.35.

The model of the European Commission (it's Directorate General Regional Policy, see [23]), is as follows:

$$r = \dot{c} \times em + i \tag{2.3}$$

where $\dot{c}$ is the growth rate of consumption (i.e. $(dc/dt)/c$), em is the elasticity of marginal utility with respect to consumption,[19] and i is the pure time preference. Using this model and assuming that the annual growth rate of Swedish consumption is 1.7 %, one arrives at a discount rate of 3.1 %.[20] It should be mentioned that the social discount rate defined in Eq. (2.3) is a general equilibrium rate corresponding to the classic infinite horizon Ramsey model that is analyzed in all advanced macroeconomics courses and nowadays in an augmented version in a typical advanced course in environmental economics. Maximizing a present value Hamiltonian yields first-order conditions that can be rearranged to yield the rate as defined in (2.3) which then equals the marginal product of real capital. The reader is referred to Eq. (7') on

[18] Using Eq. (8) and Table 7 in [22] $r = 100 \times (1.0024^{0.5} \times 1.018^{\sigma} \times 1.01 - 1)$, where σ is either 1.26 or 1. The estimate is based on GDP per capita rather than income per capita (which was not available for the considered time period). See Statistics Sweden: "National Accounts, quarterly and preliminary annual calculations".

[19] From a technical point of view em equals a coefficient of relative risk aversion. However, in [23] it seems as if em and $\dot{c}$ refer to public rather than private consumption.

[20] Using data stated in Table B.2 on page 207 in [23] but with $\dot{c} = 1.7$ (instead of $\dot{c} = 2.5$) one obtains $r = 1.7 \times 1.2 + 1.1 = 3.1$. The annual growth in real (public as well as private) consumption was around 1.7 % during the period 1970–2006 (and no data are currently available beyond 2006). See Statistics Sweden: "Detailed annual national accounts 1993–2006, some series from 1950 and 1980 (Corr. 2009-02-24)".

p. 40 in [27], with the rate of population growth set equal to zero, or Eqs. (2.8) and (2.10) in [28].

Even with moderate constant discount rates, large future damages have almost no effect on current decisions. For this reason it has become quite common to argue in favor of hyperbolic discounting; see, for example, [29, 30]. Such an approach results in a discount rate that is decreasing over time. Thus future generations are attributed lower discount rates than current ones. In the present context this approach of hyperbolic discounting does not seem to be relevant. The reason is the fact that the decision to change the water use is reversible in both directions at any point in time. At least from a theoretical point of view this means that any generation can sell or buy water use rights. Therefore, we will assume a constant discount rate. It does not seem implausible that there is a consensus emerging within EU that infrastructure project should be assessed using a discount rate of around 3–4 %; the rates mentioned above suggest such a possibility. It would greatly simplify comparisons of different infrastructure investment evaluations if they used the same discount rate in their base case evaluations. This does not prevent authors from strongly arguing for and applying different discount rates in their sensitivity analysis. In any case, we will set the social discount rate equal to 3 %; this rate is in accordance with the Swedish estimates presented above.

In the (stochastic) sensitivity analysis the discount rate will be halved and doubled, i.e. changed to 1.5 and 6 %, respectively, in order to illustrate the sensitivity of the results for the choice of discount rate. It might be noted that the lower rate is close to the one proposed by [10] in his famous "Stern Review" of the costs of climate change while the higher rate is the one proposed by [31], one of Stern's more prominent critics among economists. However, it should be stressed that they evaluate large irreversible changes that might be associated with catastrophic consequences, i.e. "projects" that are quite different from the marginal ones under consideration here. In other words, it is far from self-evident that the rates used in evaluating global climate change are relevant for our scenarios.

2.7 Results

We are now ready to collect the different items to arrive at the outcome of the cost-benefit analysis of SCENARIO 1 (SCENARIO 2 is suppressed in this Brief since from a theoretical point of view there is no principal difference between the scenarios).

The point estimate of the willingness to pay for the scenario is about SEK 300 per household per year during 5 years. This is an average across the two scenarios since we are unable to detect any significant differences between the two scenarios; recall that the contingent valuation study is a small pilot study. There are about 13 000 households in the municipality of Bollnäs. Therefore the point estimate of the aggregate present value willingness to pay of those living today amounts to SEK 18 m given a social discount rate of 3 %. It might be objected that all other things equal we *overestimate* benefits by using the highest willingness to pay estimate among our

Table 2.2 Illustration of a (point estimate) cost-benefit analysis of SCENARIO 1; million SEK

Item	Point estimate
$\sum_h WTP_h \cdot \Delta E$	26
$\Delta\pi$	−56
$-\sum_h WTA_h \cdot \Delta EM$	−2
ΔT	0
$\sum$	−32

Source own work

own estimates. However, we use this approach as a simple way of accounting for the fact that there might be a small willingness to pay also in neighboring municipalities.

We find it unlikely that there is a willingness to pay among those living in other parts of the country. After all, we consider a small project that is not associated with or affect any unique environmental values.[21] Therefore, the "local" present value willingness to pay, i.e. SEK 18 m, is assumed to coincide with the national one for the project under analysis. It might be added that if people living outside the local community are pure altruists, then their willingness-to-pay for the proposal is zero. This is so because in the contingent valuation experiment local residents pay according to their willingness-to pay, i.e. their utility levels remain unchanged. This result is proven by [8].

Future generations will also value the benefits generated by the considered project. If expected life time is 80 years, $1/80$ generations or just over 160 households enter each year, assuming a constant population over time. If their WTP coincide with the one of those living today a present value of over SEK 7 m is added to the benefits[22] so that WTP^{RB}_{NPV} amounts to SEK 26 m ($18.2 + 7.5 \approx 26$) in Table 2.2. It should be noted that in principle the considered scenario is reversible in the sense that one generation might buy the water rights while another might sell them back in order to be able to hire more teachers, more nurses to the elderly care, and so on.

The effects of SCENARIO 1 on short-term (say hourly) variations in the water flow are probably very small. Therefore, our point estimate of the associated WTP is zero.

The point estimate of the present value revenue loss of the hydroelectricity plant is SEK 59 m. We estimate that present value variable cost savings amount to about SEK 3 m. Thus the present value profits loss, denoted $\Delta\pi$ in Table 2.2, is SEK 56 m.

Finally, replacement power is likely to cause harmful emissions of some kinds of climate gases (i.e. gases that are not in the European carbon trading system), sulphur dioxide, nitrogen dioxide, and so on. Recall that the marginal electricity generator in the Nordic market typically is a fossil fuel-fired plant. These emissions cause a negative externality (unless they are optimally taxed), implying that those affected would need a compensation in order to be as well off as without the project. This

[21] If people are willing to pay for virtually all environmental projects it might be reasonable to look for the most cost-effective way of achieving similar benefits to those provided by the scenarios considered here.

[22] $18.2(1/80)32.96 \approx 7.5$, where 18.2 is the WTP of those living today and 32.96 is the present value of a SEK per year for 150 years which is the assumed time horizon.

compensation represents a cost for the project, i.e. the present value compensation, denoted $\sum_h WTA_h \Delta EM$ in Table 2.2, shows up with a minus sign. In the base case we assume that Swedes take full responsibility for any damage their actions cause (in this case through emissions from fossil-fired plants that replace the production loss at Dönje). Thus it is assumed that damage outside the country's borders is valued in the same way as domestic damage.

The estimate is based on EcoSenseLE V1.3, a web-based tool for estimating externality costs within the EU. The annual cost is estimated to EUR 3 039/GWh (about SEK 30 500). This yields a present value cost equal to SEK 4 m if the emissions continue "forever". However, it seems likely that emission restrictions will become tighter over time. We account for this fact by assuming that emissions fade away in a linear way to vanish after 20 years. Therefore the point estimate of the externality cost is SEK 2 m. Since this estimate covers some but not all types of emissions it underestimates the true cost (ceteris paribus). On the other hand, it overestimates the true cost if in the "German" price forecast scenario coal-fired plants are not replacing the production loss at Dönje. For example, the replacement power might instead be provided by pumped-storage plants. The same outcome occurs if the plants crowded out by the Danish plant in the market for carbon emission permits reduce their emissions of other harmful substances. However, there is no European or Global computable general equilibrium model linking production functions to "emission functions". Therefore we are unable to estimate the impact of the scenario on *global* general equilibrium emissions of different particulates. In the sensitivity analysis we will try to account for this uncertainty with respect to the magnitude of the emissions externality.

Since we assume that demand for electricity remains unchanged the tax term ΔT is equal to zero. Adding the different items in Table 2.2 we arrive a a point estimate of the social profitability of SCENARIO 1. According to this estimate SCENARIO 1 causes a loss to society of about SEK 30 m.

2.8 Sensitivity Analysis

A sensitivity analysis shows if the results are sensitive to substantial but plausible variations in crucial parameters. Hence it judges the robustness of the conclusions of the CBA. A one-way sensitivity analysis varies one parameter at a time. If the best estimate is used in the base case CBA, we might be able to locate extreme values in a plausible range of the parameter and use these in the sensitivity analysis. Alternatively, it might be possible to construct a confidence interval (say 95 %) for the parameter. If one is unable to find a value/range for the parameter one could perform a threshold analysis. In such an analysis the parameter is assigned a value such that the outcome of the CBA takes on a chosen value, for example, shows a zero result. If multiple univariate sensitivity analyses are undertaken they are often presented in a

Tornado diagram.[23] In such a diagram the parameters are ordered according to their impact on the result from widest range to most narrow range.

Sometimes one must undertake multivariate sensitivity analyses. For example, parameters might be correlated so that their total impact is larger or smaller than the sum of their impact according to univariate analyses. In the simplest case, one considers 2-way sensitivity analysis where two parameters are varied at a time. A typical approach is to construct a diagram in which the two parameters are varied so as to keep the result unchanged, i.e. one construct a type of indifference curves or isoquants where each curve keeps the result at a particular level. However, it is unlikely that both parameters take on their extreme values together. Therefore, one might try to find a set of parameter values that provide a likely upper bound and a lower bound, respectively, for the outcome.

There are also probabilistic sensitivity analyses where probability distributions are assumed for different parameters. Due to considerations of space we will here undertake a sensitivity analysis with respect to the tax term ΔT. Moreover we will present a probabilistic Monte Carlo simulation (with respect to other critical parameters than taxes) to shed some light on the robustness of the point estimate result presented in the previous section. Further approaches are reported in [1].

2.8.1 Demand Changes

Demand for electricity might change due to small price changes caused by the considered project. Even if such demand changes might seem unlikely they cannot be ruled out. For example, with demand functions generating realistic price elasticities, say -0.3 to -0.4, a price increase of no more than around SEK 0.1/MWh is sufficient to decrease demand by 3.7 GWh. Even if we allocate the entire demand reduction to the household sector, which accounts for 20–25 % of the total electricity consumption, a price increase of around SEK 0.4/MWh seems to be sufficient to accomplish the considered demand reduction (assuming a price elasticity of -0.3). This corresponds to EUR 0.00004/kWh, a quite small number (and of similar size in terms of USD).

Therefore, we supply a rough estimate of the magnitude of the value of such changes. For computational simplicity assuming that only households living in flats (in some parts of the country) reduce their consumption we arrive at the following estimate of the present value loss of governmental tax revenue,

$$\Delta T = \Delta x^d \int_0^{150} [282 + [480 + 282 + 50 + 200] \times 0.25] e^{-rt} dt, \qquad (2.4)$$

[23] For an illustration, see http://www.tushar-mehta.com/excel/software/tornado/decopiled_help/tornado.htm.

where $\Delta x^d < 0$ is the reduction in final demand for electricity caused by the considered project, the unit tax on households' electricity consumption is SEK 282/MWh as of fall 2010, the spot price is assumed to be SEK 480, the before VAT price a final consumer pays for energy certificates is assumed to be SEK 50/MWh, the variable transmission price (including any cost for regulating services) is assumed to be SEK 200/MWh, and VAT is currently 25 %. Vattenfall, E.ON and Fortum, the three largest players on the Swedish electricity market, have variable transmission prices of SEK 174–240/MWh for (some) consumers living in flats[24] (as of fall 2010). Here we assume that such consumers are those who following small changes in prices adjust their consumption and that the average consumer faces a variable transmission price of SEK 200/MWh. According to Eq. (2.4) we assume that all price and tax components except the spot price remain constant over time. This assumption probably causes an underestimation of the true loss since one would expect at least the unit tax on electricity to be increased over time.

This tax term has a huge impact on the outcome of the CBA. In the considered scenario the social *gross* loss increases by some SEK 65 m. This is due to the fact that electricity consumption in Sweden is subject to very high taxation. The numbers illustrate how the outcome is changed if electricity demand falls at the same rate as production at the Dönje plant. It should be stressed that in this demand reduction case there is no replacement of the electricity foregone at Dönje. Therefore the (positive) amount $\sum_h WTA_h \cdot \Delta EM$ should be added to the (negative) amount ΔT.

We probably overestimate the tax income loss because consumers might increase demand for other taxed goods than electricity (or possibly spend the same amount of money on electricity as initially, depending on the price elasticity of electricity demand); that's why we above speak of a "social *gross* loss". If the net impact is restricted to the electricity tax in Eq. (2.4) the loss is around SEK 35 m. However there is a demand-depressing loss of income through the compensation paid to the hydropower firm in order to induce it to divert water from electricity generation so these numbers might underestimate the true loss.

2.8.2 A Stochastic Sensitivity Analysis Based on Simulation Techniques

A straightforward approach to shedding some potentially interesting light on the uncertainties is to use what is sometimes called Monte-Carlo methods, or "systematic sensitivity analysis" (see [32]). Thus, rather than using a number of different parameter values (typically representing extreme outcomes), we draw values of key parameters from a distribution and then calculate net present value, given the drawn numbers. By repeating this process a large number of times, we obtain a distribution

[24] E.ON Stockholm småförbrukarprislista (SEK 239.2/MWh), Fortum enkeltariff, Stockholm (SEK 194/MWh), Vattenfall Söder enkeltariff E4 (SEK 174/MWh). These prices are available on the home pages of E.ON, Fortum, and Vattenfall, respectively (as of fall 2010).

of net present values, representing how sensitive the project is towards stochastically perturbing the key parameters. To implement the approach we use the formulas stated in Appendix B of [1].[25]

We let the interest rate, the price forecast, household annual WTP and the number of years that the negative externality is “alive”, be described by distributions. Specifically, we draw the interest rate from a truncated normal with mean 3 %, standard deviation 1 % and lower (upper) limit 1.5 (6 %). There is no particular reason to use a truncated normal, many other distributions will be useful. We use the truncated distribution to ensure that the random variables are within the stated limits. The price forecast (i.e. the constant real growth rate of the electricity price) is taken from a uniform distribution on the interval [0, 0.05] where the limits correspond to the assumed lower bound and the upper bound for the growth of the spot price. Here again one could explore different distributions, this choice simply reflects that we do not have any particular information that would motivate any other stochastic assumption. We assume that the price grows (with a constant rate) over the first twenty years, after which it is constant.

Before turning to the results, let us comment briefly on the assumptions made regarding WTP and WTA in this simulation. Household average annual WTP is drawn from a triangular distribution with limits SEK (203,399) and mode 300.83. This choice is influenced by the analysis in [18]. We could alternatively have used the estimated Weibull from the self-selected intervals. At any rate, total present value WTP depends in the simulation on two factors, the interest rate and household annual WTP. The longevity of the externality caused by replacement power is either 0, 20 or 150 years (the assumed time horizon of the project) with given probabilities.

With these assumptions, we obtain for each draw a particular value of the present value profit loss, present value aggregated WTP, present value aggregate WTA and hence a net value of the project. Each draw is so to speak “one world”, the drawn parameter configuration, in which the whole project lives. Each particular value depends in a complicated way on the stochastic assumptions made on the key parameters and the particular functional forms used. Even so, this is a very simple set-up and there are, indeed, many ways to make a more sophisticated simulation. For example, we can let the initial spot-price on electricity be a random variable, the duration of the project might be stochastic and so on and so forth. In addition, we can use other statistical (and more general) distributions. The basic purpose here is to illustrate in a simple way how uncertainty can be addressed in project evaluation. In this Brief we prefer simple and direct approaches and rather try to make the point that sensitivity analyses should always be undertaken in CBA.

In each given run we compute the social profitability of the project, given the values of four random variables. By repeating this process we thus obtain a distribution of possible outcomes that provides useful information for decision-makers with respect to possibility that the project is profitable. Another illustration is provided by what might be termed *cost-benefit acceptability curves* since they yield the probability

[25] To implement this in R, libraries `Ryacas`, `triangle` and `msm` are convenient. These libraries are available for automatic download from CRAN.

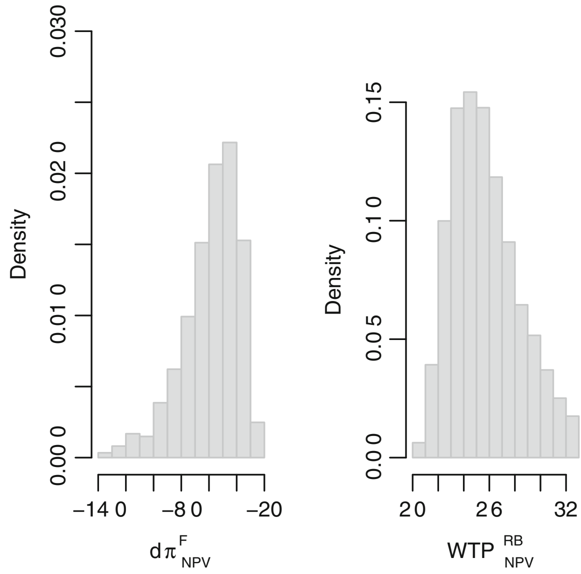

Fig. 2.4 A systematic sensitivity analysis in million SEK based on 10 000 replications. *Source* own work

that the social profitability *exceeds*, say, SEK x million. We believe a decision maker will find such curves more informative and relevant than curves (i.e. cumulative distribution functions) yielding the probability that the outcome is SEK x million or less.

Figures 2.4 and 2.5 summarizes one simulation. Figure 2.4 displays the outcome for the present value of the loss in profit and the present value WTP. There seems to be a slight skewness in the outcomes. In Fig. 2.5 the empirical version of the

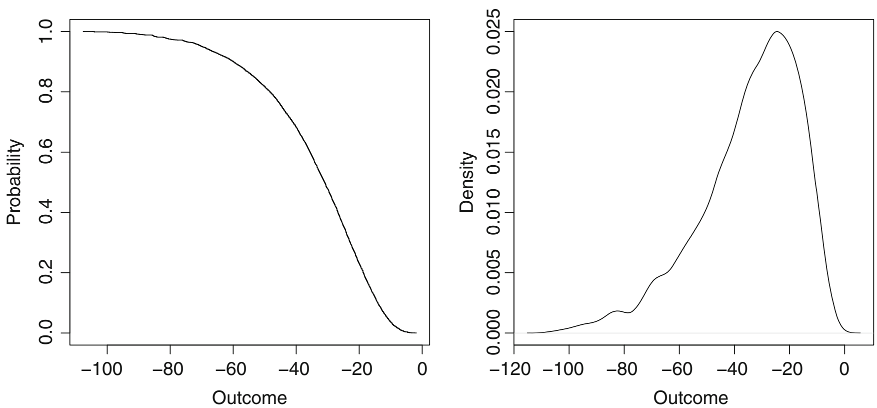

Fig. 2.5 Illustration of a cost-benefit acceptability curve and the associated probability density function from the systematic sensitivity analysis, with outcome in million SEK. *Source* own work

cost-acceptability curve, based on the simulation, is shown. There are several ways to approximate such a curve from data. Here we have simply used the empirical cumulative density functions (using the default settings in the command `ECDF` in R). The right-hand side of this figure uses the default settings of the `density` command in R. Evidently, these simulations suggest that there is very little chance for the project to be socially profitable.

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