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**Evaluation of Uncertain Projects
under Joint Implementation**

by

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ABSTRACT

Joint implementation of the Framework Convention for Climate Change means that countries may be credited emission reductions that they finance abroad in order to reduce costs. This paper discusses the aspect of uncertainty in the evaluation of such projects. According to a standard result in recent investment theory, the choice between measures may depend critically on whether the costs mainly consist of investments or can be paid as operating costs. The latter kind of projects allows for a flexibility that is attractive compared with investments that imply fixed costs. Joint implementation projects will probably involve considerable investments, while measures at home may allow for flexibility. Thus, joint implementation may be less attractive than it seems at the first glance. On the total, however, joint implementation extends the range of available measures, and thereby increases the ability to follow flexible strategies.

1 Introduction¹

The Framework Convention of Climate Change (FCCC) does not commit signatory Parties to make any efforts to reduce their emissions of greenhouse gases. However, it raises a number of general guidelines for a later extension toward a more restricted agreement. One is that it emphasises cost efficiency in the choice of climate measures. Cost efficiency in mitigating global problems implies that countries pay for abatement activities abroad if it contributes to reduce the costs. Joint implementation is the only explicitly expressed possibility to integrate climate policy across nations in the Convention.

Several industrial countries have advocated the idea of joint implementation as a strategy for which countries that pay for reductions in the emissions of greenhouse gases abroad (henceforth called financing countries) as well as countries in which the abatement takes place (henceforth called operating countries) will gain. The basic argument is straight forward: The financing country pays as long as benefits exceed costs and yields a net benefit, while the operating country may draw advantage from a better local environmental quality and embedded new technology at no cost. However, there is a need for an examination of how robust this "win-win"-argument is, at least because of the scepticism notably among developing countries and non-governmental organizations. Such an examination may take the plausible motivations for countries to carry out climate policy as its point of departure.

Whether or not to engage in joint implementation depends on the financing country's evaluation of the effect on emissions of a given amount spent on abatement abroad, which usually is uncertain. Conventional decision making applies the cost-benefit criteria; to choose the alternative with the least present value of costs. This criteria may, however, be far from optimal if one compare alternatives with different content of investment costs and operating costs, because some alternatives leave future options open while others are irreversible. Thus, the relative value of alternatives may change over time. This aspect becomes particularly important under uncertainty. Thus, one needs to examine possible abatement measures both "at home" and "abroad" from this point of view.

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This paper aims at showing the significance of this aspect for the evaluation of joint implementation projects. In the context of the analysis below, the sources of uncertainty are exogenous to both parties, and it is assumed that the problems of asymmetric information does not occur². Moreover, I do not analyse the possibility for the financing country to exploit uncertainty in order to achieve more credits than it pays for. Thus, I assume that the verification and control of projects are carried out by the financing country as if emissions of greenhouse gases enter their welfare function.

2 A general argument for joint implementation

Consider the following economy: Total utility over a given time horizon depends on the consumption level, c_s and the country's contribution to global warming, which we assume can be indexed by emissions of greenhouse gases, e_s :

$$U_t = \int_{s=t}^T u(c_s, e_s) \exp(-\delta s) ds \quad (1)$$

where δ is the pure rate of time preference. e_s is the country's contribution to a *global* problem. It may be controlled either by restricting the domestic emissions of greenhouse gases, or by reducing the emissions of greenhouse gases in another country (joint implementation), b_s . The reduction in emissions of greenhouse gases from abatement abroad is represented by a function $h(b_s)$ for which the derivatives are $h'_b < 0$ and $h''_{bb} > 0$. Domestic emissions increase with the level production, but may be reduced by abatement. Emissions are represented by $g(k_s, a_s)$, where k_s is the capital stock and a_s is resources put into domestic abatement at s . The assumptions about the first and second order derivatives are $g'_k > 0$, $g'_a < 0$ and $g''_{kk} < 0$, $g''_{aa} > 0$, respectively. The country's contribution to greenhouse gas emissions becomes:

$$e_s = g(k_s, a_s) + h(b_s) \quad (2)$$

For simplicity, economic growth is explained by capital formation alone. This means that there are no feed-back mechanism from emissions to economic

²Hagem (1994) discusses the design of incentive contracts of joint implementation projects under asymmetric information.

activity. The national product (we do not distinguish between net and gross products), $f(k_s)$ is allocated to investments, consumption and abatement at home and abroad:

$$\dot{k}_s = f(k_s) - c_s - a_s - b_s \quad (3)$$

To sum up, the model reflects a country that cares about its own contribution to the problem of global warming, but where the immediate effects of climate change from own emissions are not considered to be significant. Maximization of the integral (or “sum”) of (1) over a given period of time $(0, T)$ yields the following condition for the allocation of c_s, a_s and b_s :

$$u'_c = u'_e h'_b = u'_e g'_a \quad (4)$$

The argument supporting joint implementation follows directly from this condition: Assume first that joint implementation is *not* possible, and that the optimal solution in that case is $k^*, c^*, a^* \rightarrow e^*$. By giving this country the opportunity to engage in joint implementation, they can attain the same level of emissions with equal or less efforts if there exist projects abroad that result in more reductions per unit spent on abatement, i.e. $h'_{b=0} \leq g'_{a=a^*}$. Thus, for the same level of emissions $a^* \geq (a+b)_{ji}$, where the latter denotes necessary abatement under joint implementation. The resources that are released as a result will be allocated to consumption, investment and abatement. All these contribute directly or indirectly to utility, however at a decreasing marginal rate. Thus, an optimal allocation will add to all of them initially. For a given level of economic activity, therefore, we have $e^* \geq e_{ji}$. From this perspective, and provided that joint implementation have a non-negative net effect on the other country, joint implementation typically leads to a Pareto improvement.

In a dynamic perspective, the reference is given points of time rather than the level of states. The dynamic condition of optimality is:

$$f'_k + \frac{g'_k}{g'_a} = \delta + \mu_c \frac{\dot{c}_s}{c_s} \quad (5)$$

where $\mu_c = -c_s u''_{cc} / u'_c$ is the intertemporal elasticity of substitution, and expresses the attitude to the distribution of consumption among generations: the higher μ_c , the more attention is paid to intergenerational equity. The left hand side of (5) denotes the social rate of discount. f'_k is the rate of return on capital. The second term is the relation between the marginal increase

in emissions from capital and the marginal decrease of abatement. It can be interpreted as the implicit adjustment of social productivity as a result of emissions in optimum.

Assume that the rate of return on capital is constant and that the utility function is logarithmic, which implies that also μ_c is constant. Introduction of joint implementation will then cause an initial increase in both k and a . Since $g'_k > 0$ and $g'_a < 0$, the effect both on emissions and on economic growth here represented by \dot{c}/c may go in either direction. However, under continuing economic growth the effect of an increasing k gradually outranges the effect of increasing a which again results in an increasing rate of growth in consumption. The reason is that the marginal utility of c and e are constant while the marginal cost of abatement increases relative to the marginal productivity of capital. Thus, in the long run joint implementation may actually lead to higher emissions.

This conclusion rests, however, critically on the assumptions. Technological improvements are not included and one may question the assumptions about the second derivatives of $g(k, a)$ and $f(k)$. Extending the model slightly to include environmental feed-backs on economic activities with marginal increasing "damage" would tend to moderate the positive long-term effect on emissions. On the other hand, this possibility probably explains some of the resistance to joint implementation, namely the fear that less costly abatement leads to a higher growth which results in higher emissions.

Another question relates to the realism of including emissions directly into the utility function. It means that governments in industrialized countries really act as if increasing emissions reduce welfare as long as the ability to control the global problem by controlling their own emissions is negligible. Another reason for caring about emissions is to give a signal about the willingness to act, partly as a response to international pressure. Then the target is probably better represented by an exogenous limit to emissions, in a model where the utility depends on consumption only.³ Denote by ϵ the exogenous target. Then (2) can be replaced by

³Note, however, that although the choice of model has a significant impact on the result in the context of joint implementation, the difference of the models are more subtle. The motivation for including e_t in $w(\cdot)$ is not necessarily that the country is particularly environment friendly, but e.g. that emissions may affect the opportunities to trade with other countries. The important distinction is therefore whether the respects to emissions can be modelled from the economic activity in the country or should be assessed exogenously.

$$e_s \leq \epsilon, \tag{6}$$

and e_s is withdrawn from the utility function in (1). Solving this new problem, we obtain the same conditions, except that the shadow price of the target, η replaces the expression $u'_e e^{-\delta t}$. In other words, the shadow price can be interpreted as the implicit marginal loss of welfare due to the target.

There are, however, some crucial differences between the two cases. In the first case, where e_s enters the utility function, the solution represents the unrestricted optimum. Thus, with the given amount of initial resources, the country can not do better than following the optimality conditions. In the second example they can, if they manage to “slack” the target. Joint implementation might open for a possibility to do so if the country manages to attain more credits than they actually pay for. We will discuss this closer in the next section.

Another difference relates to the predictability of emissions. While the second case yields known future emissions if the target is given and effective, future emissions in the first case depend on measures such as future marginal productivity of capital, intertemporal elasticity of substitution, and the second derivatives of the emissions-function. These are very hard to assess. Thus, to the international society, given targets may be more attractive than relying on each country’s worries about their own emissions.

However, explicit targets will represent a limitation to a nation’s ability to reach maximum welfare over time. Even if the commitment to a target corresponds exactly to the optimal level of emissions under the welfare function given in (1), it is most unlikely that the same target will be optimal after a couple of years with economic growth, changing industrial structure and perhaps different possibilities of engaging in joint implementation projects.

3 Evaluation of projects under joint implementation

The general argument for joint implementation put forward above assumes that there exists a function $\{h : b \rightarrow e\}$ and that this function can be assessed with reasonable accuracy. How to assess it, and its sources of uncertainty have been subject to a broad discussion (Barrett (1993), Bohm (1993), Aaheim (1994), Loske and Obertür (1994)). One problem is that there are

few measures that have an effect on emissions only. The more general a measure is, the more difficult it is to isolate the marginal cost of emissions. In addition, general measures may have secondary effects, often referred to as "leakages", which makes it difficult to predict also the net effect on emissions. The effect of a carbon tax, for instance, depends on baseline assumptions, future saving ratios etc., which are impossible to assess with sufficient accuracy. Furthermore, a carbon tax will lead to substitution toward relatively less energy consuming activities, however still energy consuming, and may even affect the trade between countries. The global net effect is therefore quite open (see e.g. Bohm (1993)). This is why joint implementation will have to be restricted to projects with reasonably predictable effects.

The problems just mentioned can not be avoided completely, but may be limited by restricting the class of acceptable measures, for instance to specific abatement projects for which the marginal cost of emission reductions can be approximated on a project by project basis ("bottom-up"). Still, how successful the project will turn out is uncertain for several reasons. First, the evaluation of a project will have to be based on uncertain information, such as future prices and performance of the technology. Second, one will have to negotiate the "price" of the project with the other country. How the negotiations turn out is not only a question of input prices and technological specifications. It also depends on the information possessed by the parties, which is different for the two. Third, there are uncertainties related to the procedures in the international climate change regime: Will the Conference of the Parties accept or reject the project as a source of emission credits?

The remainder of this paper highlights uncertainties about the input variables to the evaluation of projects. In this context, uncertainty has two important aspects. First, uncertainty may represent an additional cost to a project. Second, projects involving large sunk costs may be unattractive because they fix future costs compared to more flexible alternatives. Standard cost-benefit analysis (CBA), i.e. to sum up discounted costs and benefits and check whether or not net benefit is positive, is sometimes used as a synonym for project evaluation. More careful analysis shows, however, that positive net benefit is not sufficient to start up a project, even under quite normal circumstances. One is that the future prices are non-constant. Another is that some of the variables are uncertain. To shed light over both cases we develop investment criteria both under certainty and uncertainty.

3.1 Project evaluation under certainty

Assume that one alternative for abatement of emissions is to invest an amount A , which is regarded as a “sunk cost”. We may for instance think of funding a hydro power project. The investment will replace coal-based electricity production and cause reductions in the emissions of greenhouse gases, notably CO_2 , of $[a_t, a_{t+1}, \dots, a_{t+T}]$. t is the time at which the investment is initiated, and T is the lifetime of the investment. Another alternative is to abate the same amount at a cost $p_s a_s$, ($s = 0, \dots, T$), paid each year as an operating cost until the investment is initiated. One example may be to pay the extra cost of buying gas to the power plant rather than coal, if the investments required for such a switch is negligible. The decision maker aims at minimizing the costs of abatement.

If the abatement strategy is chosen at $t = 0$, the same decision would apply for the whole period if we use ordinary CBA as a decision criterion. As we shall see, this may be misleading if one is allowed to postpone the investment, and ask when, if ever, the optimal timing of the investment is. To make this judgement at $t = 0$, it is vital to decide what period to consider: If the investment is postponed, it will last beyond T . To be able to compare an investment at $t = 0$ with the same investment at $t > 0$, therefore, one must take the whole period $(0, T + t)$ into account. To be able to compare the two cases, we need to know what the decision maker will do from T to $(T + t)$ if the investment is initiated immediately. Alternatively, we may assign a value to the investment at (T) if it is postponed at $t = 0$.

To avoid too much speculation about future abatement opportunities, we choose the latter here. The value of used capital equipment will usually depend on its age and its degree of utilization. To illustrate the effect of an end value to an investment decision, I will simplify to as great extent as possible and assume linear depreciation according to the age of the equipment. The end value at T of an investment initiated at $t (> 0)$ then becomes proportionate to its age, and the cost of the investment at t can be written:

$$A(t) = A\left[1 - \frac{t}{T}\right] \quad (7)$$

Note that if the amount to be abated each year is the same, linear depreciation according to the degree of utilization and to the age of the equipment coincide.

Denote by Q_t the net present value of the operating cost alternative in the period $(0, t)$. Then,

$$Q_t = \int_0^t p_s a_s e^{-\rho s} ds \quad (8)$$

where ρ is the discount rate. The discounted cost of abatement in the interval $(0, T)$, regardless of the choice of alternative, is

$$F(Q, t) = Q_t + A(t)e^{-\rho t} \quad (9)$$

The decision maker aims at minimizing costs. The only available control variable is to decide the optimal timing of the investment. In order to simplify further, partly because it brings the problem closer to the uncertainty case to be analysed in the next section, we shall assume that the annual cost of abatement in the operating cost case, $q_s = p_s a_s$ increases by a constant rate π . π is the increase in either the price of abatement in this case, or in the amount to be abated. Now, the value of this alternative in the period $(0, t)$ becomes

$$Q_t = \frac{q_0}{\rho - \pi} [1 - e^{(\pi - \rho)t}] \quad (10)$$

where q_0 is the cost of abatement in the operating cost case at $t = 0$. Replacing for this expression in (9) and differentiating wrt. t yields the following condition for the optimal timing of investment:

$$\frac{q_0 e^{\pi t}}{\rho A} = 1 + \frac{1}{\rho T} e^{\rho(t-T)} \quad (11)$$

Compared with the ordinary CBA-criterion, to invest if the net present value of the operating cost case exceeds the investment cost, the decision rule has changed into a strategy. The strategy is to invest when the annual cost in the operating cost case, q_t , exceeds the alternative return on the investment by a given fraction. This fraction is given by the right hand side of (11).

The CBA-criterion is applicable only in the special case where $\pi = 0$ and $T \rightarrow \infty$. Then (11) can be written as $q_0 = \rho A$, which is the CBA-criterion. If not, it may be profitable to postpone the investment till some later date. If $T \rightarrow \infty$, the strategy is to invest at the moment operating costs exceeds the annual alternative cost of the investment, i.e. $q_t = \rho A$. When

depreciation counts, the “critical value” for the investment decision increases over time if $\rho > \pi > 0$. Then, the following investment rule applies:

Invest immediately if

$$\frac{q_0}{\rho A} \geq 1 + \frac{1}{\rho T} e^{-\rho T} \quad (12)$$

Never invest if

$$\frac{q_0}{\rho A} \leq \left(1 + \frac{1}{\rho T}\right) e^{-\pi T} \quad (13)$$

Wait till (11) is fulfilled if

$$\left(1 + \frac{1}{\rho T}\right) e^{-\pi T} \leq \frac{q_0}{\rho A} \leq \left(1 + \frac{1}{\rho T}\right) e^{-\rho T}$$

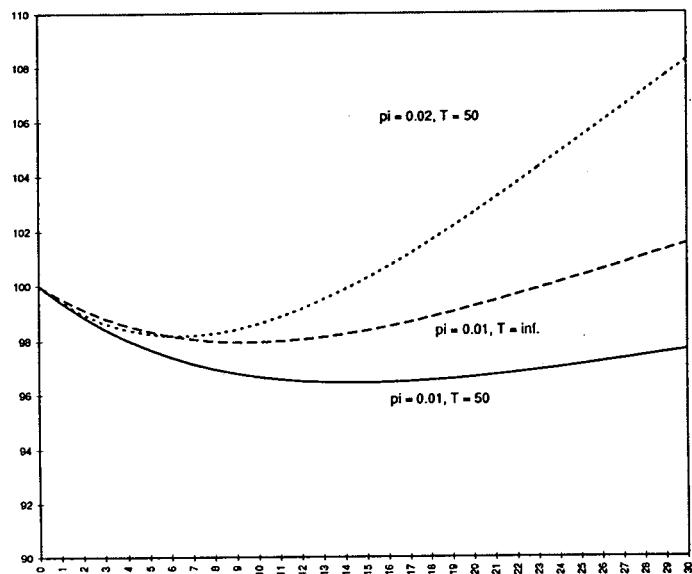
If both (12) and (13) are true: Invest immediately if $F(Q, 0) > F(Q, T)$, and never invest if not.

As for the evaluation of joint implementation, this investment rule points at the importance of extending the evaluation of projects from a study of the cost benefit ratio at some arbitrary point of time to asking the question *when* it is optimal to invest. Then the future cost profile of alternatives must be taken into account. Many abatement activities involve operating costs which are expected to change in the future, such as energy prices. It is, however, an open question whether a more careful analysis of future costs will increase or decrease the potential of joint implementation activities. That depends on the alternatives under consideration, both in the host countries and in the committed countries.

Another question is how important this question of timing is. The answer depends of course on to what extent assumptions necessary for a CBA to be appropriate are fulfilled. Some alternatives are shown in Figure 1.

Although it is possible to show that the ordinary CBA criterion may be seriously misleading, it is not obvious that it involves big practical problems. Any sensible decision maker would probably reject to make an investment now that involved twice the present cost of an alternative. The reason for putting so much effort in the above cases is to give a reference to the analysis of investment decisions under uncertainty, when the decision maker's intuition is weaker.

Figure 1. Timing of an investment under certainty



3.2 Project evaluation under uncertainty

There will be many uncertain factors related to joint implementation projects. In the investment alternative, the required amount of investment as well as the actual outcome $[a_t, \dots, a_T]$ may be uncertain. The operating cost case may exhibit uncertainties in both prices p_s and quantities a_s . All these uncertainties may require separate treatment. In addition, the reason why a_s is uncertain will have an impact on how to analyse uncertainty: If some future a_s is uncertain because there is uncertainty about how much it is necessary to abate in year s , the uncertainty is the same for the two alternatives. A different case occurs if the efficiency of the different alternatives is uncertain. Then, there are different uncertainties attached to each of them.

In this paper, we assume that the amount to be abated is known with certainty. To begin with, the uncertainty will be limited to the cost of the operating cost alternative, q_s , for instance by an uncertain price of the net abatement. In the example mentioned earlier, the uncertainty would relate to the price of gas in excess of the price of coal to the gas power plant. Also the physical amount of abatement for the operating cost alternative might

be considered uncertain. In that case the uncertainty would relate to the cost of additional abatement if the project turned out worse than expected, and the savings if it turned out better. These savings might be due to less abatement efforts in other sectors or the sales value of joint implementation credits to other countries.

In short, I will compare a certain investment A with a project with an uncertain operating costs q_s , but without any investment. I will assume that the investment alternative is infinitely living. Then effects of an arbitrary assumption about depreciation is avoided, but the assumption also makes the problem tractable, and similiar to that analysed by McDonald and Siegel (1986). This means that to invest is truly an irreversible act: Investments are "sunk costs", and once invested there is no possible way to return to the other alternative.

Recall the value of the operating cost alternative:

$$Q_t = \int_0^t q_s e^{-\rho s} ds \quad (14)$$

q_s is assumed to follow a geometric Brownian motion with drift π ,

$$dq_t = q_t(\pi dt + \sigma dz) \quad (15)$$

where $Edz = 0$ and $\sigma^2 = \text{var}[\ln(q_s/q_t)]$, $s > t$. Since the investment alternative is everlasting, we can follow Kobilá (1989) and express the expected value of the operating cost alternative by solving the integral in (14). Then,

$$EQ_t = \frac{1}{\rho - \pi} [q_0 - Eq_t e^{-\rho t}] \quad (16)$$

where q_0 , the cost of abatement at $t = 0$, is assumed to be known to the decision maker. The expected minimized value of future abatement is then

$$F(q, t) = \min_t \left\{ \frac{1}{\rho - \pi} [q_0 - Eq_t e^{-\rho t}] + Ae^{-\rho t} \right\}$$

which replaces (9) in the certainty case. This is the same as

$$F(q, t) = \frac{1}{\rho - \pi} [q_0 - \max_t E\{q_t e^{-\rho t} - (\rho - \pi)Ae^{-\rho t}\}] \quad (17)$$

This maximization problem corresponds to that of McDonald and Siegel (1986) and is further elaborated on in Dixit and Pindyck (1993). Since the

time horizon is infinite and π , q_0 and σ are all independent of t , also $F(\cdot)$ is independent of t . This implies that the passing of time has no direct impact on the the decision.

In order to simplify notation somewhat, we define

$$B = (\rho - \pi)A$$

and

$$V(q) = \max_t \{(q_t - B)e^{-\rho t}\}$$

i.e. $F(q) = 1/(\rho - \pi)[q_0 - EV(q)]$. $V(q)$ defines the time at which the difference between paying for the operating cost case into infinity and investing is at its maximum. Regarded as a function of q , we may therefore interpret it as the value of the investment option (i.e. holding the investment), given that the optimal strategy is followed. As we search for an investment strategy, our primarily interest is how $V(q)$ develops over time.

Denote by $c(q_t)$ the value of the investment option (i.e. to make the optimal decision) at t . With discrete time and time intervals of length Δt , we then have

$$V(q_t) = [c(q_t) + \frac{1}{(1 + \rho\Delta t)}EV(q_{t+\Delta t})]$$

Multiply both sides by $(1 + \rho\Delta t)$, and rearrange. Then,

$$\rho\Delta tV(q_t) = c(q)(1 + \rho\Delta t) + EV(q_{t+\Delta t}) - V(q_t).$$

Divide by Δt and let $\Delta t \rightarrow 0$. Then,

$$\rho V(q_t) = c(q_t) + E[dV(q_t)] \quad (18)$$

which is the Bellman equation.

The two alternatives can be defined by two regions within the possibility set. The region in which it is optimal to pay the operating cost q_t is clearly identified as the region in which continuation contributes positively to $V(q_t)$. In other words, $c(q_t)$ has to be positive. If $c(q_t)$ is negative, however, it would have been better to stop. Consequently, at the boundary of the continuation region, we require that

$$\rho V(q_t)dt = E[dV(q_t)] \quad (19)$$

Since q_s is a Brownian motion, $V(q_t)$ can be expanded by Ito's lemma:

$$E[dV_t] = E\left\{V'_q dq + \frac{1}{2}V''_{qq}(dq)^2\right\}$$

Taking expectations and dividing through by dt yields

$$E[dV_t] = \pi q_t V'_q + \frac{\sigma^2}{2} q_t^2 V''_{qq} \quad (20)$$

Replacing for (20) in (19), we obtain the condition for optimal timing for the investment:

$$\frac{\sigma^2}{2} q_t^2 V''_{qq} + \pi q_t V'_q - \rho V = 0 \quad (21)$$

In addition, the following conditions have to be fulfilled at the boundary, i.e. $q_t = q^*$:

$$V(0) = 0 \quad (22)$$

$$V(q^*) = q^* - B \quad (23)$$

$$V'_{q^*} = 1 \quad (24)$$

(22) simply says that if it is optimal to invest at once, the value of holding the investment is zero. (23) is "the value-matching condition": It requires that at the boundary the value of the investment option equals the expected difference between continuing the operating cost case into infinity and investing. This is exactly how we interpreted the value function. (24) is the "high-contact principle". It says that the "reward function" and the value function pasts smoothly along the q -axis. This means that the reward of a marginal increase in q equals the marginal value of the optimal choice when $q_s = q^*$. In this case this marginal total cost is 1.

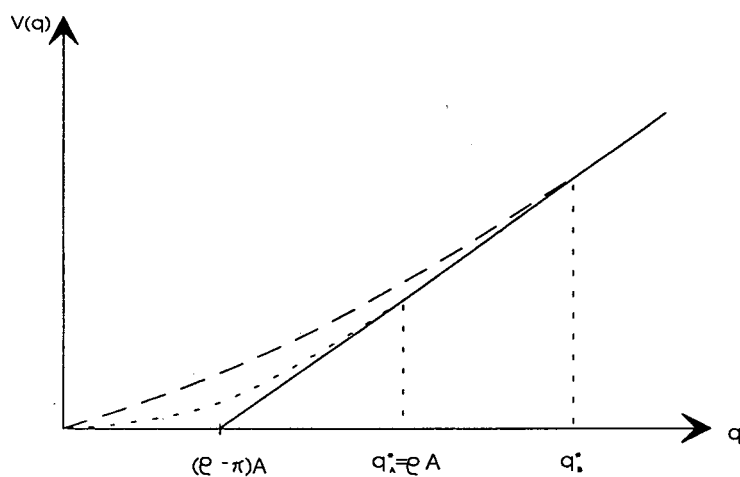
(21) - (24) allows for a complete solution of the system. Its general form is:

$$V(q_t) = a q_t^\beta \quad (25)$$

where

$$\beta = \frac{1}{2} - \frac{\pi}{\sigma^2} + \left[\left(\frac{\pi}{\sigma^2} - \frac{1}{2} \right)^2 + \frac{2\rho}{\sigma^2} \right]^{\frac{1}{2}} > 1 \quad (26)$$

Figure 2. The value of an investment



and

$$a = \frac{(\beta - 1)^{\beta-1}}{\beta^\beta} B^{1-\beta} \quad (27)$$

The critical value for the cost of the operating cost alternative can now be found by (23):

$$q^* = \frac{\beta}{\beta - 1} B \quad (28)$$

Now, $\beta \rightarrow \rho/\pi$ as $\sigma \rightarrow 0$. Therefore q^* must be higher under uncertainty than under certainty, when $q^* = \rho A$. In other words, the operating cost alternative is more attractive compared to the investment alternative if operating costs are uncertain, than under certainty.⁴

Figure 2 displays the difference between a CBA-criteria and a strategy. The straight line represents the value of initiating the investment at different values of q_t , i.e. the reward function. If $q_t = (\rho - \pi)A$, the present value

⁴This does not mean that uncertainty is attractive. The expected present value of the optimal strategy, i.e. combination of projects, increases the lower the uncertainty is.

of the two alternatives are equal. If q_t is higher, the present value of the investment alternative is lower than following the operating cost case ever after, yielding a positive value for the investment. Thus, the CBA criteria is met. However, the dotted line represents the value of a combination of the two under certainty, which is higher than to choose only one of them as long as $q \leq \rho A$. Uncertainty further moves the critical value of q^* upwards. The value of waiting to invest can be interpreted as the difference between the straight line and the $V(q)$ -curves, one curve for each case. This value expresses the loss in using the CBA-criteria if $q_t \leq q^*$. The critical value is found where this curve and the straight line touch, in accordance with the high contact principle, (24).

The operating cost alternative allows for more flexibility than the investment alternative because it leaves the decision maker the possibility to regret. This is why the critical value for the cost of the operating cost alternative is higher under uncertainty than under certainty. If q_t is slightly above the capital cost of the investment, it is nearly a 50/50 percent chance that $q_{t+\Delta t}$ will be lower than this capital cost. Thus, if we invest at that level, we run a too high risk of being stuck with the fixed cost of the investment, when the cost of the operating cost alternative is lower. If it turns out that q_t increases, we can always redo the decision of running the flexible alternative. As will be illustrated in the example below, this flexibility may be quite important, especially when q_t develops according to a geometric Brownian motion.

3.3 Examples

Due to the rather strong assumptions underlying the analysis above, it may be hard to find direct practical application of these results. However, some topical categories of abatement measures can be regarded close to either the investment alternative or the operating cost alternative. Especially since joint implementation projects must be compared with potential measures taken “at home”, one has to consider also general abatement measures as alternatives. Table 1 displays some categories of measures to mitigate climate change which may be considered either as investment projects or abatement programs with mainly operating costs. In practice, all projects will of course have some of both, but there is clearly a “bulk” of costs in either of them for the categories listed in the table, at least if we allow for a wide interpretation

Table 1. Topical categories of abatement alternatives

Description	Abatement (a)	Investment (A)	Operating cost (q)
(1) Energy saving equipment	Lower emissions from energy cons.	Cost of equipment	Negligible
(2) Forestration programme	Enhanced sinks from trees	Cost of planting	Negligible
(3) Investm. in hydro/solar power plant	Emissions from the alternative	Cost of power plant	Negligible
(4) Investm. cost of infrastructure	Lower emissions from higher energy eff.	Cost of investm.	Negligible
(5) Fuel switching e.g. from coal	Diff. in emission coefficients	Negligible	Price diff. old vs. new fuel
(6) General measures s.a. carbon tax	Emission effect of policy	Negligible	Macroec. cost of policy

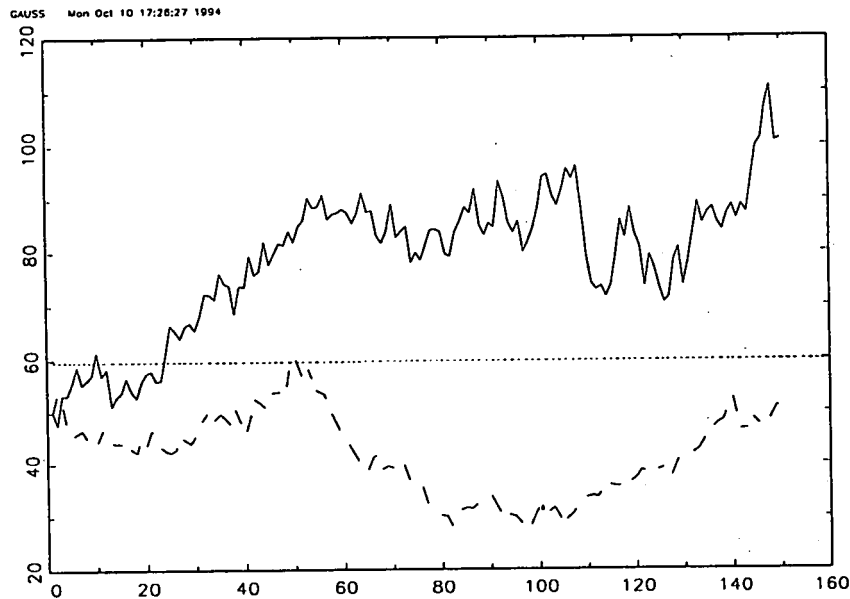
of the term negligible. In category (5), fuel-switching, investments may of course be significant. However, the relevant investment cost would be the necessary amount of investments in excess of the least cost alternative. This implies that (5) applies as an operating cost alternative when old equipment (e.g. coal fired) can be replaced. Note also that if the future operating costs of an investment alternative can be considered certain and constant, they can be included in the investment cost and regarded as such.

The four first categories can be regarded investment alternatives while the two latter consists of "operating" costs, or more precise costs of adjusting to a given emission target. Except for (6), all categories may apply as alternatives both in the financing country and in the operating country. Apparently, however, most of the measures to be considered as potential "joint implementation"-projects will probably fall into the investment alternatives.

In some cases the assumption of an infinite time horizon for the investment alternative may be problematic. Strictly speaking, investments with infinite time horizon do not exist, but for practical purposes, it is sufficient to assume that the present value of the abatement cost at T is negligible. Therefore, projects which aim at enhancing sinks by forestration, (2), will normally have a time horizon limited to the main growth period for the trees, and may not fit as an example after all.

To provide an illustration of the importance of these results, consider

Figure 3. Switch time under alternative paths for q_t



an example where energy saving (1) is compared with fuel switching (5). Assume that a country considers to invest in energy savings that will lead to an annual reduction at 100 000 tons of CO_2 . The cost of the investment, A , is 100 mill. NOK. To abate a similar amount with fuel switching, one has to pay 50 000 NOK per 1000 tons the first year (i.e 5 mill. NOK for 100 000 tons). This "price" is expected to increase by 1 percent per year, but there is a considerable uncertainty related to this increase. Assume that it is estimated to deviate by 5 percent annually from its expected path. We set the alternative return on capital to 5.5 percent.

The cost-benefit ratio for these alternatives is 1.11 in favour of the investment in energy saving. In terms of present values, the fuel switching alternative should therefore be discarded. However, during the first years of abatement it would be less expensive to switch fuels, since the cost of this alternative is below the alternative return on the cost of energy savings. It will take approximately 9 years before the investment becomes more attractive, i.e. when the cost of fuel switching equals the alternative return on the investment cost of energy savings. Thus, the energy savings plan should be

postponed at least 9 years.

If, in addition, the uncertainty is taken into account, the expected time of postponement increases substantially. The critical cost for the fuel switching alternative then increases from 55 000 NOK to about 60 000 NOK, implying a “certainty equivalent” return on capital at 6 percent. The expected switching time from fuel switching to energy saving is now 18 years. In practice, however, we don’t know when this switch is going to take place. Figure 3 displays two examples of paths for q_t that follows the same Brownian motion. The two paths varies significantly. While the upper path reaches the critical q -value after 10 years, it takes 50 years before this level is reached in the second example. According to the optimal strategy, it would be correct to invest at $t = 50$ in the latter case. Moreover, if one looked back at e.g. $t = 100$, hindsight would perhaps resulted in regrets for this decision, as the cost of the fuel-switching alternative reaches its peak exactly at this point of time. Compared with the cost-benefit criteria, however, which resulted in a clear recommendation in favour of the investment, the optimal strategy is now to postpone the investment up till 50 years.

4 Concluding remarks

Joint implementation may have a potential for making the accomplishment of efforts to mitigate climate change easier. This applies especially if countries that commit to targets of their emissions of greenhouse gases really are concerned about the problem of global warming rather than making commitments due to international pressure. A true concern will prevent the committed party from trying to make the joint implementation project look more effective than it actually is. If, on the other hand, the commitment is a result of international pressure, both parties will have incentives to make such biases in reporting the project.

Another problem related to the effect of joint implementation is the so-called leakage problem. This may be analysed from different points of view. In this paper, we shortly discussed the long-term effect on emissions from the fact that the cost of abatement decreases. It turned out that this effect might contribute to higher growth and higher emissions in long term. This effect is, however, dependent on several assumptions which may not be fulfilled. In addition, a medium term perspective seems more appropriate for an

evaluation of joint implementation due to several open questions. In such a perspective the positive effect of joint implementation projects seems rather evident.

The costs and the effects of climate measures are subject to significant uncertainty. In this paper we have restricted the analysis to compare projects mainly involving investment costs with projects mainly involving uncertain operating costs. The difference between the two arises from the fact that the operating cost alternative allows for more flexibility than an investment does. The advantage with the flexible alternative is that one may reconsider the decision when the uncertainty resolves, while the investment fixes the future cost. This effect may have a considerable effect on the optimal decision compared with the conventional cost-benefit criteria.

Joint implementation implies a significant increase of the range of possible measures to mitigate climate change from those measures available in one country, thereby extending the ability to follow flexible strategies. Financing fuel switching in other countries may in some cases be an example on topical projects for joint implementation. Perhaps equally important, however, is that investments in joint implementation will be less attractive than a present value calculation of a project would indicate, if the committed country has a flexible alternative available at home. A number of economic policy measures to restrict emissions constitute such flexible alternatives.

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