Statistics Norway
Research Department

Sverre Grepperud

Soil Conservation as an Investment in Land

Discussion Papers

Statistics Norway

Statistisk sentralbyrå

Discussion Papers No. 163 • Statistics Norway, February 1996

Sverre Grepperud

Soil Conservation as an Investment in Land

Abstract:
Most studies on the problem of optimal soil conservation have analyzed soil conservation measures as being time-limited in their effect. This paper extends previous analyses of the soil conservation decision by allowing farmers to make investments in soil conservation structures such as terraces, bundles and ditches. It shows that the main conclusions arrived at in previous studies remain valid. The long-term effects of unanticipated permanent changes in prices and discount rates may go either way independent of whether conservation measures are time-limited or have lasting effects on the soil base.

Keywords: Land degradation, investment in structures, comparative statics.

JEL classification: Q12; Q24.

Address: Sverre Grepperud, Statistics Norway, Research Department,
P.O.Box 8131 Dep., N-0033 Oslo, Norway. E-mail: sgr@ssb.no

1. Introduction[1]

The problem of land degradation, soil erosion and soil conservation is frequently analysed through optimal control models, since the choice is inherently a dynamic one, involving both intertemporal and intratemporal trade-offs. Two important policy questions are how do changes in prices and discount rates affect the incentives for soil conservation[2]. Barrett (1991) applies a model first presented by McConnel (1983) to analyse such issues, in which the soil loss rate depends directly only on cultivation intensity. More general models are provided by Barbier (1990), LaFrance (1992) and Barrett (1995) all focusing on soil conservation measures. In addition, each analysis considers additional variables which are assumed to affect land degradation and soil erosion.

Barbier (1990) and Barrett (1995) focus on the problem of soil erosion, and the stock variable in their studies is defined as soil depth. Barbier (1990) considers two control variables: first, a productive input package (productive inputs, labour, crop varieties and cropping practices) which is assumed to increase both output and soil loss and secondly, a soil conservation package assumed to reduce soil loss. Barrett (1995) considers three control variables: cultivation intensity, conservation inputs, and non-soil inputs. Here, a higher intensity of cultivation increases both output and soil loss, while conservation inputs reduce soil loss. Non-soil inputs increase output but have no direct effect on soil loss. LaFrance (1992) focuses on the problem of land degradation where the stock variable represents soil fertility and can be interpreted as an index of several soil charachteristics as e.g. infiltration rate, content of organic matter, structure, nutrient content and soil depth. LaFrance (1992) considers crop increasing/land degrading inputs (fertilizer, irrigation, ploughing) and soil conserving/crop reducing inputs[3].

A common feature in all models is that soil conservation efforts are assumed to be effective only in the time period they are implemented. In order for such measures to have lasting effects, the actual activity has to be repeated every crop season. Some conservation activities may well be described as time-limited with respect to their effectiveness, but most soil conservation measures have beneficial consequences beyond the current period. The implementation of structural conservation measures may be viewed as investments in land, since structures will have an anticipated life well beyound that of the present crop (Blaikie and Broookfield, 1987). These structural measures involve constructions such as terraces, bundles, ditches, stone walls, windbreaks and drainage systems which dampen the soil loss rate and may increase the productivity of land through higher infiltration rates and a more stable supply of water. Measures of this kind are frequently applied both in developed and less developed agriculture. In some regions such techniques have been a part of traditional agriculture, where farmers have adapted to the environment by terracing and constructing drainage channels. In other regions, the implemetation of structures has occurred in response to international and national agencies targeting soil conservation packages on more erosion-prone areas in many developing countries.

[1] I am grateful to J.T LaFrance and A. Seierstead for helpful discussions. I also thank J. Strand, K. Alfsen and P.F.

[2] See Barrett (1995) for an explanation of how macroeconomic and sectoral policies affect prices and discount rates.

[3] See LaFrance (1992) and the references therein for how irrigation and fertilizers may degrade long-term soil fertility.

This paper analyses the role and implications of soil conservation measures with lasting effects on output. Because of their durability, structures are treated as capital goods and attention is paid to the dynamics of soil-conserving capital. A partial micro economic analysis is conducted in order to study how the soil conservation decisions of land managers with perfect foresight respond to unanticipated permanent changes in prices and the discount rate. The analysis is confined to long-run influences of policy on the optimal soil conservation decision, and hence the analysis focuses on steady state[4]. The analysis addresses neither income effects nor the effect of changes in agricultural output prices on the dicount rate. Furthermore, this paper deals only with peasants who cultivate their own land, and no land-leasing contracts are considered[5].

Section 2 introduces the investment model of soil conservation. Here, the optimality conditions are derived together with a presentation of both the user cost and the shadow price of structures. In section 3 the long-term effects of changes in output price and the discount rate on the soil base are analyzed. Concluding remarks complete this investigation.

2. An investment model of soil conservation

The land degradation model presented below draws on the work of LaFrance (1992). The conservation inputs of this model are here replaced by conservation capital, while the modeling of productive inputs remains unchanged. The soil dynamics is described by the following equation,

$$\dot{S} = M - G(Z_t, K_t) \qquad (1)$$

where M is a constant representing the natural rate of soil regeneration. Z_t is a vector of productive inputs, and K_t is the stock of conservation structures. Productive inputs degrade the soil, the larger the stock of structures (K_t) the lower the soil and fertility losses[6].

The structure dynamics is as follows,

$$\dot{K} = I_t - \delta K_t \qquad (2)$$

As in neo-classical investment theory, the change in stock of structures depends on the investment rate (I_t) less the depreciation of the structures. Structures are assumed to depreciate at a constant geometric rate (δ) (replacement investments are a fixed proportion of existing capital stock).

The adoption of structure conservation measures involves different types of immediate costs for the farmer since resources are needed to construct and maintain the structures. First, labour as such is necessary,

---

4 Barbier (1990) and LaFrance (1992) consider both short- and long-term (steady state) responses to policy changes, while Barrett (1991, 1995) restricts his analysis to steady state.

5 Barrett (1995) argues in favour of the discount rate being affected by increased uncertainty about property rights.

6 Besides arresting water erosion, structures also encourage the retention of moisture and stimulate improvements in the soil's physical structure [Lutz, Pagiola and Reiche, 1994].

either hired or provided by the household. Secondly, to construct effective structures information, equipment and materials may be needed, all causing expenditures for the household. The implementation cost of the structures is assumed to be strictly convex in investment (I_t) and is represented by the function $C(I_t)$[7].

The variable Z, in addition to productive input use, may also reflect farming practices and cropping techniques. More intensive cultivation (a higher value of Z) degrades the soil and implies higher labour requirements. Examples are tillage methods (none, minimum, traditional), contour ploughing, repeated tillage, timing decisions, the burning of stubble on harvested land and the number of annual harvests. More intensive cultivation can also be interpreted as parcels of land being left fallow for shorter periods of time. R(Z), the productive cost function is convex and reflects not only costs of inputs but also the opportunity cost of labour.

In addition to soil fertility (S_t) and productive inputs (Z_t), the stock of structures (K_t) is also introduced as an argument in the production function, and is intended to represent the net result of two contradicting effects. The structures themselves take up permanently some productive land, depending on slope and gradient, this may cause reductions in output. Furthermore, there is an indirect effect of structures besides arresting soil and fertility losses in that land productivity may rise due to both a more stable supply of water and an improved infiltration rate which allows water to soak deeper into the ground. As a consequence, the immediate net effect of the stock of structures in production may go either way[8]. Output is then given by the production function, $F(S_t,Z_t,K_t)$.

Let P denote the fixed price of the farm output and r the rate of discount. The land manager's problem for a given area of land then becomes (time references will in the following be omitted for notational convenience)[9]

$$\underset{Z,I}{Max} \int_0^{\infty} \lambda_0 [PF(S,Z,K) - R(Z) - C(I)] e^{-rt} dt \tag{3}$$

[7] The assumption of a convex cost function is necessary both to avoid an all-or-nothing investment policy and to fulfill the conditions for an optimal solution in this problem (see App.1). However, in many situations it is reasonable to believe that implementation costs increase in the rate of investment. Costs associated with replacement investments are assumed to be rather low, while structure-expanding investments involve much more resources (net investment). Such investments are labour intensive and may necessitate hiring of labour and the purchase of tools. Initiation of large-scale projects may also necessitate additional costs of mobilising, organising and monitoring the labour force which implements the structures.

[8] Lutz, Pagiola and Reiche (1994) find that the construction of structures reduces the effective areas by 10 to 15 percent. White and Jickling (1992), on a study on Haiti, report that infertile subsoil is brought to the surface during construction of structures resulting in production declines.

[9] The problem presented in LaFrance (1992) is as follows:

$$\underset{Z,C}{Max} \int_0^{\infty} [Pf(s_t,x_t,y_t) - wx_t - vy_t] e^{-rt} dt \qquad s.t. \quad \dot{s} = g(x_t,y_t)$$

where s is the soil base, x productive inputs, y conservation inputs, and w and v are the market prices of x and y, respectively.

subject to (1) and (2), the initial restrictions $S(0)=S_0>0$, and $K(0)=K_0>0$ and the control restrictions $Z(0)\geq 0$, and $I\geq 0$[10].

The following assumptions are made concerning the technology;

$$Q: \quad \begin{array}{l} F_S>0,\ F_{SS}<0,\ F_Z>0,\ F_{ZZ}<0,\ F_{KK}<0,\ F_{SZ}=F_{ZS}>0 \\ R_Z>0,\ R_{ZZ}\geq 0,\ C_I>0,\ C_{II}>0,\ G_Z>0,\ G_{ZZ}\geq 0,\ G_K<0,\ G_{KK}\geq 0 \end{array}$$

where subscripts denote partial derivatives throughout the paper e.g. $F_s \equiv \partial F(S,Z,K)/\partial S$. There are diminishing returns to soil fertility, productive inputs, and the stock of structures. More soil increases the marginal productivity of productive inputs. The soil fertility rate, G(Z,K), is assumed to be convex in both productive inputs and stock of structures. This implies that the marginal increase in fertility loss due to additional use of productive inputs is highest or (unchanged) for high productive input levels. The marginal reduction in soil fertility loss due to an increase in the stock of structures is highest for low initial levels of structures. The cross partial derivative of the soil loss function will be discussed later.

Furthermore, it is natural to assume that;

$$\lim_{t\to\infty} S(t)\geq 0 \quad and \quad \lim_{t\to\infty} K(t)\geq 0 \tag{4}$$

The current value Hamiltonian associated with the problem is[11]:

$$H = \lambda_o[PF(S,Z,K) - R(Z) - C(I)] + \lambda(M - G(Z,K)) + \mu(I - \delta K) \tag{5}$$

Assuming interior solutions, the sufficient conditions for an optimal solution are (see App.1 for further details);

$$-C_I(I) + \mu = 0 \tag{6}$$

$$PF_Z(S,Z,K) - R_Z(Z) - \lambda G_Z(Z,K) = 0 \tag{7}$$

$$\dot{\lambda} - r\lambda = -PF_S(S,Z,K) \tag{8}$$

$$\dot{\mu} - r\mu = -PF_K(S,Z,K) + \lambda G_K(Z,K) + \mu\delta \tag{9}$$

Eq.(6) describes the optimal investment rate by balancing short-term costs against long-term benefits. Along the optimal investment path (optimal pattern of structure accumulation) the marginal cost reduction associated with a lower investment rate must equal the shadow value of structures. The assumption of a

[10] It is assumed throughout that the optimal investment policy for the land manager always results in $I(t)\geq 0$, since the assumption of investments in structures being irreversible seems reasonable.

[11] It follows from Q that the Hamiltonian (H) is strictly concave in S, K, Z and I, respectively.

convex cost function forces the farmer to pay attention to the future, as too rapid accumulation of structures will be costly. Eq.(7) states that the marginal costs and marginal benefits of additional use of productive inputs must be equal at optimum. The marginal cost is defined as the marginal increase in cultivation costs plus the (shadow) value of the soil lost due to that increase, while the marginal benefit is the profit obtained from a marginal increase in the use of productive inputs. Eqs.(8) and (9) determine the adjustment in the shadow values λ and μ along the optimal paths.

Expressions for the shadow values may be derived from the above conditions. Solving (8) yields the following expression for the current value multiplier (λ)

$$\lambda(t) = e^{rt} \int_t^{\infty} [PF_S(S(\tau),Z(\tau),K(\tau))e^{-r\tau}]d\tau \tag{10}$$

The shadow value of soil (λ) at optimum equals the change in income caused by a marginal reduction in soil depth at time t for all future periods. Solving (9) yields the following expression for the shadow value of structures (μ);

$$\mu_t = -e^{(r+\delta)t} \int_t^{\infty} [\lambda_\tau G_K(Z_\tau,K_\tau) - PF_K(S_\tau,Z_\tau,K_\tau)]e^{-(r+\delta)\tau}d\tau \tag{11}$$

The shadow value of structures is equal to the change in net income caused by a marginal reduction in the stock of structures at time t for all future periods, and consists of two terms. The first term of the integral is the change in the marginal soil loss rate multiplied by the current shadow value of soil, which together yield an expression for the income loss caused by a marginal reduction in K at time t due to a lower soil fertility. The second term is the loss or gain of immediate production from having a lower stock of structures. Taking the integral of the two terms implies that both losses and gains are considered for every future time period.

Comparing this model with the model of LaFrance (1992) has some interesting implications. The optimal soil conservation decision, the balancing of short-term costs against long-term benefits, differs across the two models. In LaFrance (1992), conservation inputs are employed until their marginal cost (unit cost) equals their marginal benefit, where the marginal benefit is defined as the gain associated with a higher stock of soil measured by the shadow price of land. In the investment model, by contrast, the marginal benefit associated with devoting more resources to soil conservation (investing in structures) is measured by the shadow price of structures [see (6)]. The marginal gains associated with soil conservation are no longer fully and solely reflected in the shadow price of soil, owing to the durability of soil conserving capital[12]. As with time-limited conservation inputs, an increase in the amount of resources devoted to soil conservation at time t will reduce the loss in soil fertility in all subsequent periods. In addition, the capital formation of structures will have effects on the rate of fertility loss beyond the period of time they are implemented; there will be a prevalent effect on future soil fertility until the increment in the stock of soil conserving capital is depreciated.

[12] This comparison is done under the assumption of conservation inputs and conservation structures not being arguments in the production function in LaFrance (1992) and the investment model, respectively.

In the literature soil conservation has been viewed as investments along the lines of depletion theory, through absistence from depleting a resource. Investments in this sense involve a sacrifice of current production, but leave more for future consumption. When soil conservation measures are considered to have a life beyond that of the present crop, an additional dimension of conservation measures is introduced more in line with standard investment theory, as the formation of capital in order to produce a future stream of goods at the expense of current consumption or production. Devoting more resources to soil conserving capital entails both the formation of structures (capital) and the prevention of the depreciation of the soil asset.

3. The effect of changes in output price and discount rate

To study the long-term impacts of policy reforms on the optimal soil conservation decision, shifts in both the discount rate and the output price are considered in steady state. Steady state equilibrium is attained when

$$\dot{\lambda} = \dot{\mu} = \dot{S} = \dot{K} = 0. \tag{12}$$

Letting tildes denote steady-state values, and imposing the stationarity conditions (12) on (6)-(9) implies

$$C_I(\tilde{I}) = \tilde{\mu} \tag{6'}$$

$$R_Z(\tilde{Z}) + \tilde{\lambda} G_Z(\tilde{Z},\tilde{K}) = PF_Z(\tilde{S},\tilde{Z},\tilde{K}) \tag{7'}$$

$$\tilde{\lambda} = \frac{PF_S(\tilde{S},\tilde{Z},\tilde{K})}{r} \tag{8'}$$

$$\tilde{\mu} = \frac{PF_K(\tilde{S},\tilde{Z},\tilde{K}) - \tilde{\lambda} G_K(\tilde{Z},\tilde{K})}{r+\delta} \tag{9'}$$

Equations (6')-(9') can be readily combined to derive the following steady-state optimality conditions:

$$C_I(\tilde{I})(r+\delta) = PF_K(\tilde{S},\tilde{Z},\tilde{K}) - \frac{PF_S(\tilde{S},\tilde{Z},\tilde{K}) G_K(\tilde{Z},\tilde{K})}{r} \tag{13}$$

$$R_Z(Z) + \frac{G_Z(\tilde{Z},\tilde{K})}{r} PF_S(\tilde{S},\tilde{Z},\tilde{K}) = PF_Z(\tilde{S},\tilde{Z},\tilde{K}) \tag{14}$$

The expression on the left-hand side of (13) may be viewed as the user cost of structures, where the investment costs are adjusted for discounting and depreciation, represented by r and δ, respectively. It is seen that the agricultural output price affects this optimality condition through the shadow value of soil [$\lambda(\tau)$] and through the effect of structures on immediate production [$F_K(S,K)$]. A higher discount rate also affects the same condition in two ways. One effect reduces the shadow price of soil, thus making soil conservation less attractive on the margin. This effect is the same as in Barbier (1990), LaFrance (1992), and Barrett (1995). The other effect, however, is new. Here, the user cost of structures increases as a result of a higher discount rate. This effect will also weaken the incentives for investing in soil conservation measures.

To analyse long-term consequences of permanent changes in output price and discount rate on soil fertlity, (1), (2), (13) and (14) evaluated in steady state are differentiated with respect to S, Z, K, P, and r. The following expression is derived for the impact of a change in the output price, where D>0 is shown to be required for a saddle point equilibrium (see Appendix 1 for further details).

$$\frac{d\tilde{S}}{dP} = \frac{1}{PH_{ZZ}C_{II}D}\left[rR_Z\tilde{\beta}_1 - rC_I(r+\delta)\tilde{\beta}_2 + (PF_ZG_K + PF_KG_Z)\tilde{\beta}_3\right] \tag{15}$$

The definitions of β_1, β_2, and β_3 evaluated in steady state are as follows (arguments are omitted);

$$\tilde{\beta}_1 = G_Z\delta(r+\delta)C_{II} + G_Z\tilde{\lambda}G_{KK} + G_KPF_{KZ} - G_ZPF_{KK} - G_K\tilde{\lambda}G_{KZ}$$
$$\tilde{\beta}_2 = G_KH_{ZZ} + G_ZH_{ZK}$$
$$\tilde{\beta}_3 = G_KPF_{SZ} - G_ZPF_{SK}$$

It is clear by inspection that eq. (15) cannot be signed in general, since both β_1, β_2, and β_3 are indeterminate. A permanent increase in the price of crops influences the incentives for soil conservation, but the effects could go either way. This result is equivalent to the results arrived at in the analyses of both LaFrance (1992) and Barrett (1995)[13]. Whether conservation inputs are assumed to be time-limited or having prevalent effects does not change these conclusions.

This result is not surprising when studying the effects of price changes on soil fertility for each of two input groups at a time. LaFrance (1992) has already shown that a higher price will reduce steady-state soil fertility, if conservation inputs are kept constant throughout the planning horizon. This partial result will also emerge from this model due to the similar specification of productive inputs across the two models. If productive inputs are kept constant throughout the planning horizon ((14) drops out), the same change yields a different result. A higher output price now strengthens the incentives for soil conservation, independent of the assumptions made about $F_K(S,Z,K)$ (see App.2.1). If $F_K(S,Z,K) \geq 0$, entailing that the positive effect of a more stable water supply on immediate output dominates loss of output due to loss of productive land. Two effects of a higher output price are identified, both strengthening the incentives for arresting soil depletion. First, a positive shift in the agricultural output price raises the immediate marginal benefit of building up structures. Secondly, the shadow value of the soil, and thereby the shadow value of structures, increases with the output price. If the opposite and probably more reasonable assumption is made that structures reduce immediate production, $F_K(S,Z,K)<0$, we have two opposing effects of which the second is always dominated by the first one.

We have identified two contradicting direct effects on soil fertility for each of the two input groups in the model. The fundamental reason for the different direction of change on the soil conservation incentives for the two input groups is the different implications soil conservation has on input costs. To reduce soil

---

[13] Barrett (1995) introduces a third control variable, non-soil inputs, which increase production when supplied in larger quantities, but have no direct effect on soil erosion. A change in the output price will result in adjustments also in optimal input levels for such inputs, which again have consequences for the optimal choice of cultivation intensity and conservation inputs. Hence, additional effects on the optimal soil conservation decision are introduced by such a specification of the model.

fertility rates by the build-up of conservation capital more resources are needed. To reduce the fertility loss by less use of productive inputs, less resources need to be devoted to this activity.

The effect of a higher discount rate on the steady state soil stock is as follows:

$$\frac{d\tilde{S}}{dr} = \frac{1}{H_{ZZ}C_{II}D}\left(\tilde{\gamma}_1 + \tilde{\gamma}_2 + \tilde{\gamma}_3\right) \qquad \textbf{(16)}$$

The definitions of γ_1, γ_2, and γ_3 evaluated in steady state are (arguments are omitted)

$$\tilde{\gamma}_1 = H_{ZZ}G_K(r\tilde{\mu} - \tilde{\lambda}G_K) + G_ZG_Z\tilde{\lambda} - G_KG_Z\tilde{\mu}PF_{SZ} > 0$$
$$\tilde{\gamma}_2 = G_ZG_Z(PF_{SK}\tilde{\mu}C_{II} - \tilde{\lambda}PF_{KK})$$
$$\tilde{\gamma}_3 = -(r\tilde{\mu} - 2\tilde{\lambda}G_K)H_{ZK}$$

It is clear by inspection that (16) cannot be signed, since both γ_2 and γ_3 are indeterminate. Further assumptions on the technology are needed to reach definite conclusions. This result is more surprising in view of the partial effects for each of the two input groups. The effect of a higher discount rate on steady-state soil fertility is negative both for productive inputs (see LaFrance, 1992) and for conservation structures (see App.2).

However, an increase in the discount rate does not unequivocally reduce steady-state soil fertility in the full model. The reason is that a general model introduces additional (indirect) effects arising from both the fertility loss function and the production function, not present when analysing each input group separately. This result also coincides with that of Barrett (1995). Barbier (1990) and LaFrance (1992), on the other hand, find that the direction of change will in general be unambiguous, as more myopic households will keep a lower long-term stock of the soil resource, the higher the discount rate is. Their results, however, arise from different assumptions on technology[14]. Barbier assumes a positive cross partial derivative of the soil loss function, implying that an increase in conservation inputs increases soil loss attributable to an increase in productive inputs. "Barbier makes this assumption upon observing that farmers often adopt soil conservation measures only after they switch to producing more erosive (and valuable crops) [Barrett, 1995, p.14]". Barrett (1994) and LaFrance (1992) make a more appealing assumption, namely that conservation mitigates the soil loss effect (soil degrading effects) of cultivation (productive inputs).

Sufficient conditions for the discount rate to weaken the incentives for soil conservation in the investment model are: $F_{SK} \geq 0$ and $H_{ZK} = PF_{ZK} - \lambda G_{ZK} < 0$, with both γ_2 and γ_3 becoming positive. $G_{ZK} < 0$ is not a sufficient condition for a lower steady-state soil fertility in response to a higher discount rate in the investment model. Even if $G_{ZK} > 0$, additional assumptions on changes in the marginal productivities of

[14] LaFrance's conclusion follows from his assumptions on the current value Hamiltonian function ($H_{xy} < 0$).

both soil and productive inputs from more conservation capital are needed, to reach a unique conclusion[15]. Hence, a higher discount rate can in principle both improve or worsen the incentives for soil conservation. The conclusion in Barrett (1995) remains true despite the additional negative effect on soil fertility identified in the investment model, which arises from a higher discount rate through the user cost of structures.

Although the effect of discount rate changes on soil conservation could go either way, smooth functional forms will in general yield a negative effect. It is then reasonable to expect that higher discount rates in general will dampen the incentives for soil conservation. One important condition for arriving at a different conclusion is that the marginal fertility loss due to more intensive cultivation is strongly reduced with the accumulation of structures .

4. Conclusion

The main result of this analysis concerns the treatment of soil conservation methods as an investment in land. In the literature so far, erosion-preventing inputs and soil conservation practices have been analyzed within a framework where they are assumed to be time-limited with respect to their effectiveness in arresting soil erosion and soil depletion. However, many of the important methods for conserving the soil have effects beyond the current crop season. As a consequence, the investment decision for a farmer becomes more than just a reduction in the actual soil loss rate during an interval of time, which in turn keeps soil depth higher over a longer term. Investment in soil conservation measures is also the build-up of soil conserving capital which mitigates the degradation of land over a longer period of time. For such conserving measures the shadow value of structures (or the user cost of structures) describes the optimal soil conservation decision.

The investment model studied in this paper introduces both a different optimality condition for soil conservation and some new effects of changes in prices and discount rates on the optimal steady-state soil stock compared to previous models. However, analysing soil conservation as an investment in land will not contradict the main conclusions arrived at in other models on land degradation and soil erosion. In order to predict the outcome of the optimal soil conservation decision, detailed information is needed on input use, the actual soil conservation measures applied and production technology.

The results from this study are not surprising considering the similarity in structure between conservation inputs and conservation structures. The investment model approaches the model of LaFrance (1992) as the rate of depreciation goes to one, entailing that structures have no effect beyond the period of time in which they are implemented. The fundamental cause for the opposite direct effects of price changes across the two input groups on optimal soil conservation is found in the way inputs costs are connected to the endeavors of reducing fertility losses. For both conservation inputs and structures more resources are needed to combat fertility losses. For productive inputs, however, the effect is opposite. Here, less input use is needed to reduce soil mining.

---

[15] In LaFrance (1992), more conservation inputs are assumed to reduce the marginal productivity of both productive inputs and soil.

The total effect of changes in the discount rate on the optimal soil conservation decision is also in principle ambiguous. An additional negative effect on soil depth from increases in the discount rate is identified when analysing soil conserving capital rather than conservation inputs. However, the presence of this effect is not sufficient for predicting that a rise in the discount rate will unambiguously lower the equilibrium soil depth.

The model considered assumes that farming practices, conservation methods and inputs can be classified as either crop increasing/land degrading or crop reducing/land improving. This need not always be the case. The net effect from some inputs may be beneficial both for the resource base and immediate output. One example could be chemical fertilizers. The application of fertilizers will provide land with a denser vegetation providing a better protection of soils, thereby preventing water run-off. In some cases this effect could offset the land degrading effects arising from the use of the same input (acidification). Another example is organic fertilizers such as dung and crop residues, which improve soil fertility by supplying organic matter and nutrients to the soil and at the same time protect land cover from erratic onsets from wind and rain. The introduction of such crop increasing/land improving inputs could well be analyzed within our model. As mentioned above, the partial effect of an increase in the output price will depend on the way in which input costs are connected to actions implemented for reducing fertility losses. As is the case for crop reducing/land improving inputs, additional input use is needed to reduce the degradation of soils for crop increasing/land improving inputs. Thus, the partial effect of a higher output price on steady-state soil fertility will be positive for such inputs.

Appendix 1

Sufficient conditions for problem (3)

If $\lambda_o=1$, the sufficient conditions for (6)-(9) to describe an optimal solution are [Seierstad and Sydsæter 1987, Theorem 13];

$$a)\ \lim_{t\to\infty}\, [e^{-rt}\lambda(S-S^*)+e^{-rt}\mu(K-K^*)] \geq 0 \quad \textit{for all admissable S and K.} \tag{A.1.1}$$

Since (S*(t), K*(t), λ(t), μ(t)) → (S,K,λ,μ) when t→∞ (see below) and given assumption (4), A.1.1. holds.

$$b)\ H^* = \max_{IZ} H \text{ is concave in } (S,K). \tag{A.1.2}$$

I is defined from (6) and will maximise H since C(I) is strictly convex. Z is defined from (7) and maximises H since H is strictly concave in Z. A sufficient condition for A.1.2. is that H is concave in (S,K,I,Z).

Sufficient and necessary conditions for a local saddle point equilibrium for problem (3)

Substituting for I from (6) and for Z from (7), the dynamic evolution of the system along an optimal path can be expressed by (1), (2), (8) and (9). Linearising the system in steady state yields the following conditions for this model with two state variables (four-dimensional problem)[Feichtinger and Hartl, 1986; Satz 5.4]

$$T = -\delta(r+\delta) - \frac{1}{H_{ZZ}C_{II}}\left(G_Z C_{II}(rH_{SZ} - G_Z H_{SS} + H_{KK}H_{ZZ} - PF_{KZ}H_{KZ} - (\lambda)^2(G_{KZ})^2\right) \quad < 0$$

$$D = \frac{1}{H_{ZZ}C_{II}}\left(A + B + C + E + F\right) \quad > \quad 0$$

where:

$$A = \delta(r+\delta)G_Z C_{II}\left(G_Z PF_{SS} - rPF_{SZ}\right)$$

$$B = PF_{SS}\left(G_K G_K PF_{SZ} - G_Z G_{KK} r\tilde{\lambda} + G_K G_{KZ} r\tilde{\lambda} - rPF_{KZ}\right)$$

$$C = PF_{SS}\left(G_Z G_K PF_{ZK} - G_Z G_K \tilde{\lambda} G_{ZK} - G_K G_K - G_K G_Z \tilde{\lambda} G_{KZ} + G_Z G_Z G_{KK} + PF_{KZ} G_Z - PF_{KK} G_Z G_Z\right)$$

$$E = -PF_{SK}\left(PF_{ZS} G_Z G_K + PF_{ZS} G_Z G_K + PF_{ZK} G_Z r - F_{ZK} G_Z G_Z - r\tilde{\lambda} G_Z G_{ZK}\right)$$

$$F = \frac{PF_{SK}PF_{ZS}}{H_{ZZ}}\left(G_Z G_Z \tilde{\lambda} G_{KK} - G_Z G_Z \tilde{\lambda} G_{KZ} C_{II}\right)$$

$$\textit{and} \quad \frac{T^2}{4} - D \geq 0$$

These conditions must be met for the system to have two negative and two positive real roots. T is defined from the following expression of determinants

$$T_1 \equiv \begin{vmatrix} \frac{\partial \dot{S}}{\partial S} & \frac{\partial \dot{S}}{\partial \lambda} \\ \frac{\partial \dot{\lambda}}{\partial S} & \frac{\partial \dot{\lambda}}{\partial \lambda} \end{vmatrix} + \begin{vmatrix} \frac{\partial \dot{K}}{\partial K} & \frac{\partial \dot{K}}{\partial \mu} \\ \frac{\partial \dot{\mu}}{\partial K} & \frac{\partial \dot{\mu}}{\partial \mu} \end{vmatrix} + 2 \begin{vmatrix} \frac{\partial \dot{S}}{\partial K} & \frac{\partial \dot{S}}{\partial \mu} \\ \frac{\partial \dot{\lambda}}{\partial K} & \frac{\partial \dot{\lambda}}{\partial \mu} \end{vmatrix}$$

while D is the determinant of the following Jacobian matrix for our system

$$\begin{pmatrix} \frac{\partial \dot{S}}{\partial S} & \frac{\partial \dot{S}}{\partial K} & \frac{\partial \dot{S}}{\partial \lambda} & \frac{\partial \dot{S}}{\partial \mu} \\ \frac{\partial \dot{K}}{\partial S} & \frac{\partial \dot{K}}{\partial K} & \frac{\partial \dot{K}}{\partial \lambda} & \frac{\partial \dot{K}}{\partial \mu} \\ \frac{\partial \dot{\lambda}}{\partial S} & \frac{\partial \dot{\lambda}}{\partial K} & \frac{\partial \dot{\lambda}}{\partial \lambda} & \frac{\partial \dot{\lambda}}{\partial \mu} \\ \frac{\partial \dot{\mu}}{\partial S} & \frac{\partial \dot{\mu}}{\partial K} & \frac{\partial \dot{\mu}}{\partial \lambda} & \frac{\partial \dot{\mu}}{\partial \mu} \end{pmatrix}$$

Since the conditions are local, it is necessary for the starting points of the state variables (initial values) to be close to (S,K) to be sure of the existence of an optimal path converging to the equilibrium path.

Appendix 2

Comparative statics, keeping productive inputs (Z) constant

$$\frac{d\tilde{S}}{d\tilde{P}} = \frac{G_K(F_S G_K - rF_K)}{D} = -\frac{C_I(r+\delta)r}{D} > 0 \qquad \text{(A.2.1)}$$

$$\frac{d\tilde{S}}{dr} = \frac{G_K(\tilde{\lambda} G_K - \mu r)}{D} < 0 \qquad \text{(A.2.2)}$$

$$\textit{where} \quad D = G_K(PF_{SS}G_K + rPF_{KS}) < 0$$

References

Barber, R. (1984): An assessment of the dominant soil degradation processes in the Ethiopian Highlands: Their impacts and consequences,. EHRS Working Paper 23, FAO/MoA.

Barbier, E.B. (1990): The farm level economics of soil conservation: The uplands of Java, *Land Economics* **66** No. 2, 199-211.

Barrett, S. (1991): Optimal soil conservation and the reform of agricultural pricing policies, *Journal of Development Economics* **36**, 167-187.

Barrett, S. (1996): "Microeconomic responses to macroeconomic reforms in the optimal control of soil erosion", forthcoming in P. Dasgupta and K.G. Maler (eds.), *The environment and emerging development issues,* Oxford: Clarendon Press.

Blaike, P. and Brookfield, H. (1987): *Land degradation and society*, Methuen & co, New York.

Chirinko, R.S. (1991): Business fixed investment spending: A critical survey of modeling strategies, empirical results, and policy implications (Preliminary manuscript)

Feichtinger, G. and Hartl, R.F. (1986): *Optimale kontrolle okonomischer prozesse*, Berlin: Walter de Gruyter.

LaFrance, J.T. (1992): Do increased commodity prices lead to more or less soil degradation? *Australian Journal of Agricultural Economics* **36**, No.1, 57-82.

Kamien, M. and Schwartz, N. (1981): *Dynamic optimization: The calculus of variations and optimal control in economics and management*, North Holland, New York.

Lutz, E., Pagiola, S. and Reiche, C. (1994): Economic and institutional analyses of soil conservation projects in Central America and the Caribbean. World Bank Environment Paper No. 8. The World Bank.

McConnel, K.E. (1983): An economic model of soil conservation, *American Journal of Agricultural Economics* **65**, 83-89.

Seierstad, A. and Sydsæter, K. (1977): Sufficient conditions in optimal control theory, *International Economic Review* **18**, No.2, 367-391.

Seierstad, A. and Sydsæter, K. (1987): *Optimal Control Theory with Economic Applications*, North Holland, Amsterdam.

White, T.A., and Jickling, J.L. (1992): An economic and institutional analysis of soil and water conservation in Haiti, Environment Department Divisional Working Paper No. 1992-33, The World Bank.

Issued in the series Discussion Papers

42 R. Aaberge, Ø. Kravdal and T. Wennemo (1989): Unobserved Heterogeneity in Models of Marriage Dissolution.

43 K.A. Mork, H.T. Mysen and Ø. Olsen (1989): Business Cycles and Oil Price Fluctuations: Some evidence for six OECD countries.

44 B. Bye, T. Bye and L. Lorentsen (1989): SIMEN. Studies of Industry, Environment and Energy towards 2000.

45 O. Bjerkholt, E. Gjelsvik and Ø. Olsen (1989): Gas Trade and Demand in Northwest Europe: Regulation, Bargaining and Competition.

46 L.S. Stambøl and K.Ø. Sørensen (1989): Migration Analysis and Regional Population Projections.

47 V. Christiansen (1990): A Note on the Short Run Versus Long Run Welfare Gain from a Tax Reform.

48 S. Glomsrød, H. Vennemo and T. Johnsen (1990): Stabilization of Emissions of CO_2: A Computable General Equilibrium Assessment.

49 J. Aasness (1990): Properties of Demand Functions for Linear Consumption Aggregates.

50 J.G. de Leon (1990): Empirical EDA Models to Fit and Project Time Series of Age-Specific Mortality Rates.

51 J.G. de Leon (1990): Recent Developments in Parity Progression Intensities in Norway. An Analysis Based on Population Register Data

52 R. Aaberge and T. Wennemo (1990): Non-Stationary Inflow and Duration of Unemployment

53 R. Aaberge, J.K. Dagsvik and S. Strøm (1990): Labor Supply, Income Distribution and Excess Burden of Personal Income Taxation in Sweden

54 R. Aaberge, J.K. Dagsvik and S. Strøm (1990): Labor Supply, Income Distribution and Excess Burden of Personal Income Taxation in Norway

55 H. Vennemo (1990): Optimal Taxation in Applied General Equilibrium Models Adopting the Armington Assumption

56 N.M. Stølen (1990): Is there a NAIRU in Norway?

57 Å. Cappelen (1991): Macroeconomic Modelling: The Norwegian Experience

58 J.K. Dagsvik and R. Aaberge (1991): Household Production, Consumption and Time Allocation in Peru

59 R. Aaberge and J.K. Dagsvik (1991): Inequality in Distribution of Hours of Work and Consumption in Peru

60 T.J. Klette (1991): On the Importance of R&D and Ownership for Productivity Growth. Evidence from Norwegian Micro-Data 1976-85

61 K.H. Alfsen (1991): Use of Macroeconomic Models in Analysis of Environmental Problems in Norway and Consequences for Environmental Statistics

62 H. Vennemo (1991): An Applied General Equilibrium Assessment of the Marginal Cost of Public Funds in Norway

63 H. Vennemo (1991): The Marginal Cost of Public Funds: A Comment on the Literature

64 A. Brendemoen and H. Vennemo (1991): A climate convention and the Norwegian economy: A CGE assessment

65 K.A. Brekke (1991): Net National Product as a Welfare Indicator

66 E. Bowitz and E. Storm (1991): Will Restrictive Demand Policy Improve Public Sector Balance?

67 Å. Cappelen (1991): MODAG. A Medium Term Macroeconomic Model of the Norwegian Economy

68 B. Bye (1992): Modelling Consumers' Energy Demand

69 K.H. Alfsen, A. Brendemoen and S. Glomsrød (1992): Benefits of Climate Policies: Some Tentative Calculations

70 R. Aaberge, Xiaojie Chen, Jing Li and Xuezeng Li (1992): The Structure of Economic Inequality among Households Living in Urban Sichuan and Liaoning, 1990

71 K.H. Alfsen, K.A. Brekke, F. Brunvoll, H. Lurås, K. Nyborg and H.W. Sæbø (1992): Environmental Indicators

72 B. Bye and E. Holmøy (1992): Dynamic Equilibrium Adjustments to a Terms of Trade Disturbance

73 O. Aukrust (1992): The Scandinavian Contribution to National Accounting

74 J. Aasness, E. Eide and T. Skjerpen (1992): A Criminometric Study Using Panel Data and Latent Variables

75 R. Aaberge and Xuezeng Li (1992): The Trend in Income Inequality in Urban Sichuan and Liaoning, 1986-1990

76 J.K. Dagsvik and S. Strøm (1992): Labor Supply with Non-convex Budget Sets, Hours Restriction and Non-pecuniary Job-attributes

77 J.K. Dagsvik (1992): Intertemporal Discrete Choice, Random Tastes and Functional Form

78 H. Vennemo (1993): Tax Reforms when Utility is Composed of Additive Functions

79 J.K. Dagsvik (1993): Discrete and Continuous Choice, Max-stable Processes and Independence from Irrelevant Attributes

80 J.K. Dagsvik (1993): How Large is the Class of Generalized Extreme Value Random Utility Models?

81 H. Birkelund, E. Gjelsvik, M. Aaserud (1993): Carbon/energy Taxes and the Energy Market in Western Europe

82 E. Bowitz (1993): Unemployment and the Growth in the Number of Recipients of Disability Benefits in Norway

83 L. Andreassen (1993): Theoretical and Econometric Modeling of Disequilibrium

84 K.A. Brekke (1993): Do Cost-Benefit Analyses favour Environmentalists?

85 L. Andreassen (1993): Demographic Forecasting with a Dynamic Stochastic Microsimulation Model

86 G.B. Asheim and K.A. Brekke (1993): Sustainability when Resource Management has Stochastic Consequences

87 O. Bjerkholt and Yu Zhu (1993): Living Conditions of Urban Chinese Households around 1990

88 R. Aaberge (1993): Theoretical Foundations of Lorenz Curve Orderings

89 J. Aasness, E. Biørn and T. Skjerpen (1993): Engel Functions, Panel Data, and Latent Variables - with Detailed Results

90 I. Svendsen (1993): Testing the Rational Expectations Hypothesis Using Norwegian Microeconomic Data Testing the REH. Using Norwegian Microeconomic Data

91 E. Bowitz, A. Rødseth and E. Storm (1993): Fiscal Expansion, the Budget Deficit and the Economy: Norway 1988-91

92 R. Aaberge, U. Colombino and S. Strøm (1993): Labor Supply in Italy

93 T.J. Klette (1993): Is Price Equal to Marginal Costs? An Integrated Study of Price-Cost Margins and Scale Economies among Norwegian Manufacturing Establishments 1975-90

94 J.K. Dagsvik (1993): Choice Probabilities and Equilibrium Conditions in a Matching Market with Flexible Contracts

95 T. Kornstad (1993): Empirical Approaches for Analysing Consumption and Labour Supply in a Life Cycle Perspective

96 T. Kornstad (1993): An Empirical Life Cycle Model of Savings, Labour Supply and Consumption without Intertemporal Separability

97 S. Kverndokk (1993): Coalitions and Side Payments in International CO_2 Treaties

98 T. Eika (1993): Wage Equations in Macro Models. Phillips Curve versus Error Correction Model Determination of Wages in Large-Scale UK Macro Models

99 A. Brendemoen and H. Vennemo (1993): The Marginal Cost of Funds in the Presence of External Effects

100 K.-G. Lindquist (1993): Empirical Modelling of Norwegian Exports: A Disaggregated Approach

101 A.S. Jore, T. Skjerpen and A. Rygh Swensen (1993): Testing for Purchasing Power Parity and Interest Rate Parities on Norwegian Data

102 R. Nesbakken and S. Strøm (1993): The Choice of Space Heating System and Energy Consumption in Norwegian Households (Will be issued later)

103 A. Aaheim and K. Nyborg (1993): "Green National Product": Good Intentions, Poor Device?

104 K.H. Alfsen, H. Birkelund and M. Aaserud (1993): Secondary benefits of the EC Carbon/ Energy Tax

105 J. Aasness and B. Holtsmark (1993): Consumer Demand in a General Equilibrium Model for Environmental Analysis

106 K.-G. Lindquist (1993): The Existence of Factor Substitution in the Primary Aluminium Industry: A Multivariate Error Correction Approach on Norwegian Panel Data

107 S. Kverndokk (1994): Depletion of Fossil Fuels and the Impacts of Global Warming

108 K.A. Magnussen (1994): Precautionary Saving and Old-Age Pensions

109 F. Johansen (1994): Investment and Financial Constraints: An Empirical Analysis of Norwegian Firms

110 K.A. Brekke and P. Børing (1994): The Volatility of Oil Wealth under Uncertainty about Parameter Values

111 M.J. Simpson (1994): Foreign Control and Norwegian Manufacturing Performance

112 Y. Willassen and T.J. Klette (1994): Correlated Measurement Errors, Bound on Parameters, and a Model of Producer Behavior

113 D. Wetterwald (1994): Car ownership and private car use. A microeconometric analysis based on Norwegian data

114 K.E. Rosendahl (1994): Does Improved Environmental Policy Enhance Economic Growth? Endogenous Growth Theory Applied to Developing Countries

115 L. Andreassen, D. Fredriksen and O. Ljones (1994): The Future Burden of Public Pension Benefits. A Microsimulation Study

116 A. Brendemoen (1994): Car Ownership Decisions in Norwegian Households.

117 A. Langørgen (1994): A Macromodel of Local Government Spending Behaviour in Norway

118 K.A. Brekke (1994): Utilitarism, Equivalence Scales and Logarithmic Utility

119 K.A. Brekke, H. Lurås and K. Nyborg (1994): Sufficient Welfare Indicators: Allowing Disagreement in Evaluations of Social Welfare

120 T.J. Klette (1994): R&D, Scope Economies and Company Structure: A "Not-so-Fixed Effect" Model of Plant Performance

121 Y. Willassen (1994): A Generalization of Hall's Specification of the Consumption function

122 E. Holmøy, T. Hægeland and Ø. Olsen (1994): Effective Rates of Assistance for Norwegian Industries

123 K. Mohn (1994): On Equity and Public Pricing in Developing Countries

124 J. Aasness, E. Eide and T. Skjerpen (1994): Criminometrics, Latent Variables, Panel Data, and Different Types of Crime

125 E. Biørn and T.J. Klette (1994): Errors in Variables and Panel Data: The Labour Demand Response to Permanent Changes in Output

126 I. Svendsen (1994): Do Norwegian Firms Form Extrapolative Expectations?

127 T.J. Klette and Z. Griliches (1994): The Inconsistency of Common Scale Estimators when Output Prices are Unobserved and Endogenous

128 K.E. Rosendahl (1994): Carbon Taxes and the Petroleum Wealth

129 S. Johansen and A. Rygh Swensen (1994): Testing Rational Expectations in Vector Autoregressive Models

130 T.J. Klette (1994): Estimating Price-Cost Margins and Scale Economies from a Panel of Microdata

131 L. A. Grünfeld (1994): Monetary Aspects of Business Cycles in Norway: An Exploratory Study Based on Historical Data

132 K.-G. Lindquist (1994): Testing for Market Power in the Norwegian Primary Aluminium Industry

133 T. J. Klette (1994): R&D, Spillovers and Performance among Heterogenous Firms. An Empirical Study Using Microdata

134 K.A. Brekke and H.A. Gravningsmyhr (1994): Adjusting NNP for instrumental or defensive expenditures. An analytical approach

135 T.O. Thoresen (1995): Distributional and Behavioural Effects of Child Care Subsidies

136 T. J. Klette and A. Mathiassen (1995): Job Creation, Job Destruction and Plant Turnover in Norwegian Manufacturing

137 K. Nyborg (1995): Project Evaluations and Decision Processes

138 L. Andreassen (1995): A Framework for Estimating Disequilibrium Models with Many Markets

139 L. Andreassen (1995): Aggregation when Markets do not Clear

140 T. Skjerpen (1995): Is there a Business Cycle Component in Norwegian Macroeconomic Quarterly Time Series?

141 J.K. Dagsvik (1995): Probabilistic Choice Models for Uncertain Outcomes

142 M. Rønsen (1995): Maternal employment in Norway, A parity-specific analysis of the return to full-time and part-time work after birth

143 A. Bruvoll, S. Glomsrød and H. Vennemo (1995): The Environmental Drag on Long- term Economic Performance: Evidence from Norway

144 T. Bye and T. A. Johnsen (1995): Prospects for a Common, Deregulated Nordic Electricity Market

145 B. Bye (1995): A Dynamic Equilibrium Analysis of a Carbon Tax

146 T. O. Thoresen (1995): The Distributional Impact of the Norwegian Tax Reform Measured by Disproportionality

147 E. Holmøy and T. Hægeland (1995): Effective Rates of Assistance for Norwegian Industries

148 J. Aasness, T. Bye and H.T. Mysen (1995): Welfare Effects of Emission Taxes in Norway

149 J. Aasness, E. Biørn and Terje Skjerpen (1995): Distribution of Preferences and Measurement Errors in a Disaggregated Expenditure System

150 E. Bowitz, T. Fæhn, L. A. Grünfeld and K. Moum (1995): Transitory Adjustment Costs and Long Term Welfare Effects of an EU-membership – The Norwegian Case

151 I. Svendsen (1995): Dynamic Modelling of Domestic Prices with Time-varying Elasticities and Rational Expectations

152 I. Svendsen (1995): Forward- and Backward Looking Models for Norwegian Export Prices

153 A. Langørgen (1995): On the Simultaneous Determination of Current Expenditure, Real Capital, Fee Income, and Public Debt in Norwegian Local Government

154 A. Katz and T. Bye(1995): Returns to Publicly Owned Transport Infrastructure Investment. A Cost Function/Cost Share Approach for Norway, 1971-1991

155 K. O. Aarbu (1995): Some Issues About the Norwegian Capital Income Imputation Model

156 P. Boug, K. A. Mork and T. Tjemsland (1995): Financial Deregulation and Consumer Behavior: the Norwegian Experience

157 B. E. Naug and R. Nymoen (1995): Import Price Formation and Pricing to Market: A Test on Norwegian Data

158 R. Aaberge (1995): Choosing Measures of Inequality for Empirical Applications.

159 T. J. Klette and S. E. Førre: Innovation and Job Creation in a Small Open Economy: Evidence from Norwegian Manufacturing Plants 1982-92

160 S. Holden, D. Kolsrud and B. Vikøren (1995): Noisy Signals in Target Zone Regimes: Theory and Monte Carlo Experiments

161 T. Hægeland (1996): Monopolistic Competition, Resource Allocation and the Effects of Industrial Policy

162 S. Grepperud (1996): Poverty, Land Degradation and Climate Uncertainty

163 S. Grepperud (1996): Soil Conservation as an Investment in Land

Statistics Norway
Research Department
P.O.B. 8131 Dep.
N-0033 Oslo

Tel.: + 47 - 22 86 45 00
Fax: + 47 - 22 11 12 38

ISSN 0803-074X

Statistics Norway
Research Department