THE KOREAN ECONOMIC REVIEW
Volume 14, Number 2, Winter 1998

ECONOMIC MODELLING OF SOIL CONSERVATION: AN ENDOGENOUS GROWTH APPROACH

KWAN SOO KIM*

This paper first develops the model, based on endogenous growth argument, in which environmental quality is included as input and thus makes possible the explanation of issues related to resource allocation and its impacts on the environment. Second, it analyzes the relationship between land market performance and underinvestment by incorporating information about soil quality into the analytical framework. It extends existing literature on the economic modelling of soil conservation in several ways. In particular, adopting an endogenous growth approach with soil quality as a state variable enables us to explicitly characterize the underlying externality associated with the problem of land resource management. The policy implications of this paper are also relevant. It identifies the effects of different policy tools on soil conservation outcomes and their impacts on social welfare change in relation to land market performance.

JEL Classification: Q24, O40.
Keywords: Soil Conservation, Endogenous Growth, Land Market Imperfection

I. INTRODUCTION

The problem of soil erosion and of associated forms of agricultural land degradation has been a subject of research in several scholarly disciplines. Indeed, environmental problems caused by soil erosion are severe in many parts of the world. In the U.S., soil erosion has been recognized as a primary source of water pollution (USDA, Agricultural Outlook 1995) as over 43% of non-point source water pollution can be attributed to it (Ribaudo 1986). In developing

Received for publication: Apr. 1, 1998. *Revision accepted:* June 10, 1998.

* Research Associate, Dept. of Agricultural and Applied Economics, Univ. of Wisconsin-Madison, Taylor Hall, 427 Lorch St., Madison WI 53705., USA. I am grateful to Ian Coxhead, Bradford L. Barham, Jean-Paul Chavas, and William R. Provencher for insightful comments on earlier drafts. I also thank the referees for many useful comments and suggestions. Financial support from a Hatch grant is gratefully acknowledged.

countries, problems caused by soil erosion seem even more serious; as the annual value of on-site and off-site costs of soil erosion are estimated at 4 per cent of GDP in Indonesia, 9% in Burkina Faso and as high as 17% in Nigeria (Barbier and Bishop (1995)).

The linkage between soil erosion and environmental deterioration, and the potential connection between land degradation and a decline in the future productive capacity of agricultural land, require us to assess these issues in a broader context than one solely defined by private optimization. This is because these degradation processes can generate both on-farm and off-farm costs. According to neoclassical economic theory, farmers will use land in such a way as to equate the marginal private cost of production with the marginal private benefit. However, in the presence of both on-farm and off-farm costs and the absence of internalizing mechanisms on these externalities, the social marginal cost of agricultural production will be greater than the marginal private cost of agricultural production realized by farmers. If this is true, then, from society's standpoint, it follows that agricultural land is overutilized and that private and social optima diverge.

This divergence has been the focal point of considerable economic research aimed at modelling soil conservation and the economic costs of land degradation in the context of both developed and developing economies (Barbier(1990), Burt (1981), Clarke(1992), Coxhead(1995), Lafrance(1992), McConnell(1983), and Walker (1982)). Most studies address the challenge of how to explicitly characterize the linkage between farmer behavior and environmental consequences. Surprisingly, however, an endogenous growth approach has not yet been widely used in the analysis of environmental or natural resource degradation problems such as the soil degradation problem, even though externalities are among the main features of environmental and resource degradation problems.

Using an endogenous growth approach, this paper first presents a generic model in which environmental quality is included as an input, more specifically a key stock variable that influences both production and consumption outcomes. The central question will be to ask how dynamic resource allocation decisions that involve environmental externalities differ between individual agents in a decentralized decision making context and those of a social planner. The second part of the paper provides an alternative means of explaining underinvestment in soil conservation by developing a more specific version of the endogenous growth model. This specific endogenous model extends the existing literature in two ways. First, by explicitly incorporating both soil quality and land market imperfections into an analytical framework, the model enables us to provide an alternative explanation for underinvestment in soil conservationthat—that is, one that does not rely on idiosyncratic characteristics such as subjective discount rates (McConnell(1983)).[1] In addition, the model also enables us to identify the

[1] If soil quality cannot be accurately observed, then this may prevent the complete capitalization

effects of different policy tools (e.g., income support and investment subsidy programs) on soil conservation outcomes and their impacts on social welfare change in relation to land market performance.

The remainder of this paper consists of 4 sections. Section 2 reviews the relevant literature, and concludes by motivating an alternative endogenous growth model of agricultural resource allocation and environmental outcomes. Section 3 presents the generic endogenous growth model and explores the case in which individual agents do not have sufficient private incentives to invest in the improvement of environmental quality. Section 4 applies this model to the specific problem of soil conservation decisions by focusing on the implications of land market imperfections for investment decisions. Clearly, the intertemporal links provided by a state variable such as soil quality will enrich the analysis by providing a dynamic element not normally taken into account. Section 5 provides a summary and conclusions.

Ⅱ. LITERATURE REVIEW

2.1. Models of Farm-level Resource Allocation and Land Degradation

Formal analyses of the economics of agricultural soil conservation began with the optimal control models by McConnell(1983) and Burt(1981). McConnell's study provides a basic model of farmer behavior toward soil conservation by developing a constrained dynamic optimization model of the optimal private and social paths of soil erosion. In his setting, farmers choose inputs in order to maximize the present value of output stream given by:

$$J=\int_0^T[pg(t)f(s(t),x(t),z(t))-cz(t)]e^{-rt}dt+R[x(T)]e^{-rT}, \qquad (1)$$

where r is the discount rate, p is the output price, $g(t)$ is a neutral technical change shifter, $s(t)$ is soil loss, x(t) is soil depth, and $z(t)$ is an index of a variable inputs with costs c. R(·) stands for the resale value of the farm at the terminal time and depends on soil fertility. Soil loss, included in the production function, determines the time path of soil depth in the following way:

$$\dot{x}(t)=k-s(t), \qquad (2)$$

where k is the exogenous natural rate of soil regeneration. McConnell's main contribution is to identify the conditions under which farmers (as private agents) optimally make production decisions in which $s(t)$ exceeds both the natural

---

of soil-conserving investments into land prices, thereby reducing incentives to undertake such investments.

regeneration rate k and the socially optimal rate. McConnell argues that an individual farmer might not adopt the optimal path of soil use that a social planner would because the farmer's rate of time discount exceeds that of the social planner. In spite of the elegance and parsimony of McConnell's model, however, this characterization of on-farm market failure is not particularly appealing-discount rates are subjective, and it is not clear why they should necessarily diverge in the suggested direction. Furthermore, the validity of this discount rate argument depends on land market performance because, as Clarke (1992) argues, resale value may capture difference between private and socially optimal depletion rates. In addition, the McConnell model ignores off-farm market failure such as pollution externalities from loading streams with waste material.

Burt's model is similar to McConnell's except in the set up of the state equations, and it is quite specific to one localized region. One limitation is the way that the control variable is determined in the model. Since the percentage of land planted to wheat is a control variable, the only means to influence the values of state variables is by allocating land between wheat and the less erosive crop. This, as a result, produces unambiguous increase in soil erosion when wheat price increases. Nevertheless, the underlying model by Burt is reasonably general and it still provides insights in the soil erosion literature.

While Burt emphasizes crop choice, Walker(1982) introduces the time of adoption of conservation practices as a control variable in order to examine the soil degrading effects of cultivation techniques. One of his contributions to the soil conservation literature is the use of crop yield as an alternative measure of topsoil depth; future yields will decline as farmers use more erosive practices. However, it is clearly desirable to use inherent soil quality instead of yields (as a proxy variable) because the magnitude of yields can be altered by changing some management practices (for example, by applying N fertilizer) in the short run whereas the underlying soil quality can not (*Kim et al.* (1997)).

A more recent literature has proposed models which allow for soil quality-improving investment. According to these models (Barbier(1990), Clarke (1992), LaFrance(1992)), farmers can not only reduce the stock of soil (i.e., soil quality) by intensive cultivation, but they can also improve it by means of soil-conserving investments. Although such a model was originally proposed by McConnell, it was not formally analyzed by him because of the assumption about the fixed level of soil quality. Obviously, this new approach represents another way of conceptualizing the problem of soil degradation. Following the notation used by McConnell and Clarke for the sake of comparison, the problem can be stated as:

$$J = \max_{z, I} \int_0^{\infty} e^{-rt}\{P[f(x, z, I)] - c(w)\}dt \tag{3}$$

$$s.t. \ \dot{x} = g(k, z, I),$$

where P is a vector of output prices, x is an index of soil quality, z is a vector of variable inputs to current production, I is an investment. $c(w)$ indicates production costs where w is a vector of input prices. One of prominent features of this type of model is that soil quality can also be enhanced by investment, so that $\partial g/\partial I > 0$. Hence, given the above framework, the McConnell and Burt models become special cases where $\partial g/\partial I = 0$ (see Coxhead (1995) for details).

This alternative approach that recognizes the potential for improving or depleting soil quality, distinguishes modern land degradation models from the previous models, which treat soil as a renewable resource which regenerates only by exogenous means. The alternative view clearly extends the range of the farmers' options with respect to production and resource allocations by including the investment decision, i.e., the choice of whether to allocate resources between current and future production, in addition to the technology and crop decisions. However, these aforementioned models all omit off-farm externalities due to land degradation outcomes, and as such they do not incorporate the full effects of dynamic land degradation on subsequent consumption and production outcomes.

2.2. Toward an Alternative Model: An Endogenous Growth Approach

Endogenous growth models can generate long-term economic growth without depending on exogenous changes in technology that drive the standard Solow growth model. In their specification of production functions, endogenous growth models emphasize the role of externalities generated by changes in variables such as government spending (Barro(1990)), human capital (Lucas(1988)) and knowledge spillovers (Romer(1990)). Yet, as mentioned above, endogenous growth techniques have not been widely adopted in the analysis of environmental or natural resource degradation problems,[2] even though externalities are one of the main features of environmental and resource degradation problems. As we will show below, an endogenous growth approach enables us to explicitly characterize the linkage between farmer behavior and its environmental consequences.

The following section models the growth of an economy with environmental quality as an input to production and consumption, using an endogenous growth approach.[3] Environmental quality is improvable through investment, and the rate

[2] Krauskraemer(1985) and Smith(1977) developed optimal growth models where natural and environmental resources are explicitly considered. Ayers(1988) studied optimal investment policies with exhaustible resources using concepts from information theory. Mohtadi and Roe(1992) discussed the relationship between endogenous growth, health and the environment.

[3] Three recent studies by Mohtadi and Roe(1992), Ligthart and Ploeg(1994), and Elbasha and Roe(1995) have introduced environmental externalities into endogenous growth models. The first identifies a negative relationship between the growth rate and the quality of environment by focusing on the role of environment which affects the utility function through health factors.

of environmental quality degradation is endogenously determined in this model.[4]

Ⅲ. A BASIC ENDOGENOUS GROWTH MODEL WITH ENVIRONMENTAL QUALITY AS AN INPUT

The model presented in this section builds on Barro'(1990) view that government spending might create positive spillovers to the marginal productivity of capital, and adapts it by identifying the positive spillovers of environmental quality in terms of its marginal contributions to both production and utility. It also adapts Lucas'(1988) model of human capital externality by considering another accumulable factor, i.e., environmental quality, in the production function, so that the production of an economy can exhibit at least constant returns to scale (CRTS) to accumulative factors (capital and environmental quality).

Consider a closed economy where the representative, infinite-lived agent seeks to maximize overall utility, given by:

$$U=\int_0^{\infty} u(c_t, A_t)e^{-rt}dt, \tag{4}$$

where c_t is consumption per person and r is the constant rate of time preference (the discount rate). A_t is an index of environmental amenity which is assumed to be a function of environmental quality, $A_t=g(Q_t)$, where Q_t is environmental quality. For simplicity, population is assumed to be constant. I use a utility function which exhibits constant relative risk aversion (CRRA):

$$u(c_t, A_t)=\frac{\sigma}{\sigma-1}(c_t^{\zeta}g(Q_t)^{1-\zeta})^{\frac{\sigma-1}{\sigma}}, \tag{5}$$

where $\sigma>0$, so that marginal utility has a constant intertemporal elasticity of substitution[5] (σ) and $0<\zeta<1$. For simplicity, assume that $g(Q_t)$ is a linear function of Q_t of the form: $g(Q_t)=\phi Q_t$. Notice that in DCE, an index of

---

Ligthart and Ploeg also show that without government intervention, the decentralized market outcome is inefficient since pollution, as a byproduct of production, produces a negative environmental externality. However, neither study captures the potential for investments aimed at improving environmental quality. Elbasha and Roe represent the quality of the environment as a flow variable in order to reduce the complexity of their model. However, it is arguably much more reasonable to include environmental quality as a state variable since it is not generally the case that environmental quality will be determined entirely by current actions.

[4] In Smith(1977)'s model, the rate of environmental degradation is determined exogenously through functional restrictions rather than endogenously derived.

[5] The intertemporal elasticity of substitution indexes the willingness of consumers to substitute consumption across periods given the degree of intertemporal variation in the price of consumption.

environmental amenity is given by its current level. Output per agent, y_t, can be produced according to the following Cobb-Douglas production function:

$$y_t = \Phi_t k_t^{1-\beta} Q_t^{\beta}, \; \Phi_t = \pi Q_t^{\gamma}, \tag{6}$$

where k_t is capital per agent, Q_t is environmental quality per agent and Φ_t is a shift factor, assumed to be a function only of environmental quality. Notice that both k_t and Q_t are measured in effective units. In DCE, Φ_t is modelled as a given value, reflecting the fact that an individual agent might not be able to capture the full marginal productivity benefit of improvements in environmental quality. In CO, by contrast, the production function shift factor (Φ_t) is not fixed but is a function of environmental quality. This distinction implies that individual agents ignore positive spillovers when they choose Q_t,[6] but a social planner captures these spillovers. This characterization of the production function may not be consistent with the cases where some form of internalization occurs. However, we can still think of these as the same form of production function with low value of π and γ.

For simplicity, assume that each agent works a fixed amount of time, which means that there is no labor-leisure choice and no alternative use of capital, i.e., no bond market and no trade in capital. The law of motion for capital is

$$\dot{k}_t = \alpha_t (y_t - c_t) - \delta k_t, \tag{7}$$

where α_t is a proportion of total savings allocated to investment for capital accumulation and δ is the depreciation rate of capital. Environmental quality at time t (Q_t) is assumed to evolve over time in response to the following three factors. First, $(1-\alpha_t)$ portions of savings are invested for improving environmental quality. Notice that in DCE, since it is plausible to argue that an individual agent does not have an incentive to invest her savings for the improvement of environmental quality in general, α_t takes the value 1. Again, α_t may not equal 1 in the most of agricultural applications due to some form of internalization efforts (for example, a farmer is likely to have an incentive to undertake some soil-conserving investments under conditions shown in the following section). Second, in the absence of environmental quality investment, environmental quality will regenerate at the rate; $\eta \cdot Q_t, \eta \geq 0$. Finally, assume that environmental

[6] There is plenty of evidence of the harmful impact of environmental degradation on the marginal productivity of human capital especially through the health status of human capital: food chain, air and water pollution, deterioration of capacity of the upper atmosphere to filter harmful radiation. Therefore, improving environmental quality exhibits positive spillovers in terms of marginal productivity. Clearly, positive spillovers of environmental quality in terms of the marginal utility of consumption are also present.

quality will deteriorate at a rate proportional to the current level of production: $(\theta \cdot y_t), 0 < \theta < 1$. Thus, environmental quality evolves over time according to:

$$\dot{Q}_t = \eta Q_t - \theta y_t + \omega(1-a_t)(y_t - c_t), \tag{8}$$

where ω indicates an investment efficiency index for improving environmental quality, and the dot indicates the time derivative d/dt.

Each agent takes the levels of environmental amenity (A_t) and the shift factor of the production function (Φ_t) as given, and maximizes utility (4) subject to the constraints (6), (7), (8), initial conditions for capital and environmental quality, and transversality conditions. The current value Hamiltonian associated with this maximization problem is given by:

$$H = u(C_t, \bar{A}_t) + \lambda_t^1[a_t(\Phi_t k_t^{1-\beta} Q_t^{\beta} - c_t) - \delta k_t] + \lambda_t^2[\eta Q_t - \theta \Phi_t k_t^{1-\beta} Q_t^{\beta} + \omega(1-a_t)(\Phi_t k_t^{1-\beta} Q_t^{\beta} - c_t)], \tag{9}$$

whereis λ_t^1 is the current shadow value of a unit of capital and λ_t^2 is the current shadow value of a unit of environmental quality. In this optimal control problem, we have two control variables (c_t, a_t) and two state variables (k_t, Q_t). According to the maximum principle, the optimal paths of $c_t, a_t, k_t, Q_t, \lambda_t^1$ and λ_t^2 satisfy the following first order and transversality conditions:

$$H_c = 0 \rightarrow u_c(\cdot) = \lambda_t^1 \text{ or } u_c(\cdot) = \omega\lambda_t^2, \tag{10}$$

$$H_a = 0 \rightarrow \lambda_t^1 = \omega\lambda_t^2, \tag{11}$$

$$-H_k = \dot{\lambda}_t^1 \rightarrow \dot{\lambda}_t^1 = \lambda_t^1[(\delta + r) - a_t f_k] + \lambda_t^2[\theta f_k - \omega(1-a_t) f_k], \tag{12}$$

$$-H_Q = \dot{\lambda}_t^2 \rightarrow \dot{\lambda}_t^2 = \lambda_t^2[\theta f_Q - \omega(1-a_t) f_Q - \eta + r] - \lambda_t^1 a_t f_Q, \tag{13}$$

$$\lim_{t\to\infty} e^{-rt}\lambda_t^1 k_t = 0, \quad \lim_{t\to\infty} e^{-rt}\lambda_t^2 Q_t = 0, \tag{14}$$

where f_k is the marginal productivity of capital and f_Q is the marginal productivity of environmental quality. Equation (10) indicates that the marginal utility of consumption, i.e., the current shadow value of consumption, must equal the current shadow value of capital along the optimal path. This condition makes sense since one unit of consumption and one unit of capital are exchangeable in this economy. According to (11), investment can be optimally allocated among two alternatives (direct investment for capital accumulation and an alternative investment for improving environmental quality). Equations (12) and (13) describe the optimal paths of the current shadow value of capital and environmental quality. Equation (14) denotes the transversality conditions.

The maximization of the representative agent's overall utility in (4) implies that the growth rate of consumption at each time t is characterized by combining (10), (11) and (12) to obtain.

$$g_c^{DCE}=\frac{\sigma}{1-\zeta+\sigma\zeta}\left[\frac{(\omega-\theta)}{\omega}f_k-(\delta+r)\right], \tag{15}$$

where g_c^{DCE} is the growth rate of consumption in DCE. Notice that the growth rate of consumption is positively correlated with the marginal productivity of capital and an investment efficiency index for improving environmental quality (ω). On the other hand, this growth rate is negatively correlated with the depreciation rate of capital (δ), the discount rate (r) and the depletion-output ratio (θ). Alternatively, combining (10), (11) and (13), we can derive Euler's equation, given by:

$$g_c^{DCE}=\frac{\sigma}{1-\zeta+\sigma\zeta}[(\omega-\theta)f_Q+\eta-r]. \tag{16}$$

Observe that the marginal value of a unit of environmental quality in DCE ($f_{Q\ in\ DCE}=\beta\pi k_t^{1-\beta}Q_t^{\beta+r-1}$) is less than the marginal value of a unit of environmental quality under CO ($f_{Q\ in\ co}=(\beta+r)\pi k_t^{1-\beta}Q_t^{\beta+r-1}$). In other words, in DCE, individual agents fail to capture the full marginal value of environmental quality since they have no incentive to internalize the underlying externalities; hence the growth rate of consumption gets lower. This clearly shows the advantage of adopting an endogenous growth approach-it explicitly characterizes the linkage between individual agent behavior and growth of an economy.

The command optimum solution highlights the following features of the model. First, environmental quality gives some positive marginal utility, the magnitude of which depends on the size of weight (ζ) and a parameter Ψ. Second, output per agent, y_t, can be produced according to the following C-D production function:

$$y_t=\Phi_t k_t^{1-\beta}Q_t^{\beta},\ \ \Phi_t=\pi Q_t^r \Rightarrow y_t=\pi k_t^{1-\beta}Q_t^{\beta+r}. \tag{17}$$

Equation (17) implies that a social planner understands the full interactions between environmental quality, Q_t, and output, y_t. Third, a social planner has an incentive to invest savings for the improvement of environmental quality in general. So, α_t takes values between 0 and 1. Comparing Euler equations under DCE and CO yields:[7)]

$$g_c^{CO} = g_c^{DCE} + \frac{\sigma}{1-\zeta+\sigma\zeta}\left[(\omega-\theta)\gamma\pi k_t^{1-\beta}Q_t^{\beta+\gamma-1} + \omega\left(\frac{\zeta}{1-\zeta}\right)\left(\frac{c_t}{Q_t}\right)\right] \tag{18}$$

Equation (18) implies that the growth rate of consumption under CO is greater than that of under DCE since the second term is non-negative provided that $\omega > \theta$.[8] This equation implies that in the steady state, the level of consumption under CO can grow faster than under DCE holding other parameters constant. So, clearly, if society provides some institutions which can internalize the underlying environmental externalities, then society can be better off in the steady state. The results derived here are intuitive and interesting since they provide an explicit explanation as to why the government intervention in the problems related to the environment could play an important role in improving the long-run growth path.

In this section, I have investigated the interactions between endogenous growth and environment in a simple modelling context where a society as a whole derives positive marginal utility as well as positive production spillovers from environmental quality. In contrast to the other studies (Ligthart and Ploeg(1994), Mohtadi and Roe(1992)),[9] this model shows that economic growth and environmental quality can be complements rather than substitutes, conditional on the inequality $(\omega > \theta)$.

Ⅳ. AN ALTERNATIVE MODEL FOR SOIL CONSERVATION

This section develops a model which explores the implications of land market imperfections on farmers' optimal soil conservation decisions. Also, given the clear motivation of government interventions as implied by the generic model, the effects of policy tools such as an investment subsidy and price support program are examined. The main features of this model include (i) the characterization of land market imperfections as a function of unobservability of

---

[7] Combining (10)-(12), (14), and (13)′ produces the following Euler equation under CO in (18)′:

$$-H_Q = \dot{\lambda}_t^2 \rightarrow \dot{\lambda}_t^2 = \lambda_t^2[\theta f_Q - \omega(1-\alpha_t)f_Q - \eta + r] - \lambda_t^1\alpha_t f_Q - u_Q(\cdot), \tag{13′}$$

$$g_c^{CO} = \frac{\sigma}{1-\zeta+\sigma\zeta}\left[(\omega-\theta)(\beta+\gamma)\pi k_t^{1-\beta}Q_t^{\beta+\gamma-1} + \omega\left(\frac{\zeta}{1-\zeta}\right)\left(\frac{c_t}{Q_t}\right) + \eta - r\right], \tag{18′}$$

where $f_Q = (\beta+\gamma)\pi k_t^{1-\beta}Q_t^{\beta+\gamma-1}$. Notice that the optimal path for the current shadow value of environmental quality in (13)′ is modified from (13) to reflect (i) the full interactions between environmental quality and output and (ii) the marginal contribution of environmental quality to the overall utility of society.

[8] In general, it can be argued that investment efficiency (ω) is greater than the soil depletion rate (θ). Otherwise, an economy would be worse off by increasing investment because an output increase by investment would generate soil depletion greater than the improvement achieved by the investment.

[9] They argue that there exists a negative relation between growth rate and environmental quality.

soil quality, and (ii) the identification of soil quality, which is not assumed to be constant, as a key state variable.

4.1. The Structure of the Dynamic Model of Soil Conservation

Assume that a representative farmer works his land to maximize the present value of the utility stream from agricultural production plus the value of agricultural land at the end of planning horizon. Note that the end of the planning horizon can be regarded as a selling time to a farmer who decides to exit. Therefore, land price at the end of planning horizon becomes the salvage value of land. Then, a farmer seeks to maximize overall utility and the salvage value at time T given by:

$$\int_0^T u(c_t, A_t)e^{-rt}dt + S(Q_T)e^{-rT}, \tag{19}$$

where c_t is consumption, A_t is an index of environmental amenity which is assumed to be a function of soil quality $[A_t = g(Q_t)]$, r is the constant rate of time preference (the discount rate), and $S(Q_T)$ is the salvage value of agricultural land at time T as a function of soil quality (Q_T). This salvage value depends on land market performance; if land markets are perfect, then this value should be equal to the intrinsic value of agricultural land; otherwise, the salvage value and the intrinsic value are not the same.[10]

There has been much attention to the effects of available policy tools on soil conservation outcomes (Clarke(1992), Coxhead(1995)). In this effort, we specify the following equality in such a way that it allows for examining the effects of an income support and investment subsidy program on soil conservation outcomes. Consumption (c_t) is made available from production and it is equal to output minus investment:

$$y_t = (1+\tau)\{c_t + (1-\mu)I_t\}, \tag{20}$$

where y_t is income from production and I_t is investment, μ is a parameter which summarizes government's subsidy policy on soil-conserving investments $(0 \le \mu \le 1)$, and τ is a parameter which indicates an income support policy (the corn price

[10] Consider the following two cases to illustrate the effects of asymmetric information on land market performance,. First, under perfect observability of soil quality (perfect information), the salvage value of land must equal to $S(Q_T)$. In this scenario, a dynamic optimization problem with a truncated planning horizon becomes an optimization problem with an infinite planning horizon (Clarke(1992)). Second, under imperfect observability of soil quality (asymmetric information), the salvage value could be denoted by $S(\overline{Q}_T)$ where $\overline{Q}_T$ indicates the average value of soil quality at time T.

support program can be regarded as a type of income support policy). When τ is greater than 0, a farmer who produces y_t is able to enjoy additional income of $\tau \cdot y_t$. With these two policy parameters, the model can be used to analyze the effect of two conflicting policies in terms of soil conservation outcomes.

We continue to make the assumption that utility can be specified by a constant relative risk aversion (CRRA) function:

$$u(c_t, A_t) = \frac{\sigma}{\sigma - 1}(c_t^{\zeta} A_t^{1-\zeta})^{\frac{\sigma-1}{\sigma}}, \tag{21}$$

where $\sigma > 0$, so that marginal utility has a constant intertemporal elasticity of substitution (σ) and $0 < \zeta < 1$. A_t is an index of environmental amenity which is assumed to be a function of soil quality, $A_t = g(Q_t)$. Following the general model in the previous section, assume that $g(Q_t)$ is a linear function of Q_t of the form: $g(Q_t) = \Psi Q_t$. Notice that in DCE, A_t (environmental amenity out of soil quality) is given by its current level. In other words, an individual agent takes the current level of A_t as given in her maximization problem.

Because prices are given and constant by assumption, y_t can be interpreted as output in this economy. Net output (y_t) can then be expressed as the following Cobb-Douglas production function and opportunity costs associated with investment:

$$y_t = \Phi_t Q_t^{\beta} - \gamma(1-\mu)I_t, \quad \Phi_t = \delta Q_t^{\alpha}, \quad \alpha, \beta, \gamma, \delta > 0, \tag{22}$$

where Φ_t is the shift factor of production function (assumed to be a function only of soil quality), Q_t is the level of soil quality, γ captures opportunity costs of investment in terms of output given price $(0 < \gamma \leq 1)$ and $(1-\mu)I_t$ indicates the level of soil-conserving investment after taking account of the investment subsidy. Better soil quality is beneficial to crop production, so α and β take on positive values. However, accounting for the fact that a soil-conserving investment requires a sacrifice of current production (for example, because planting alfalfa as a mean for conserving soil quality reduces corn output in a given plot), the investment term is subtracted in a linear fashion from the production function. As in the general model of the previous section, in DCE, Φ_t is given because an individual farmer fails to capture the full marginal productivity of soil quality whereas in CO this shift factor is not taken as given any more but is viewed as a function of soil quality. In other words, individual agents ignore positive spillovers when they choose Q_t, but a social planner recognizes these spillovers. Off-site externalities associated with soil erosion would be a good example for the above specification of the shift factor in DCE and CO, because soil quality of a certain land might be easily deteriorated by soil erosion from a neighbor's land when positive spillovers are ignored (as in DCE).

Based on the discussion in the general model, soil quality at time t is assumed to evolve over time in response to the following three factors. First, investments can improve soil quality (the parameter ω indicates investment efficiency). Second, soil quality itself regenerates at the rate; $\eta \cdot Q_t$, $\eta \geq 0$. Finally, assume that soil quality will deteriorate at a rate proportional to the current level of production; $(\theta \cdot y_t)$, $\theta \geq 0$. This says that for example, planting corn (which is more lucrative than planting alfalfa) will reduce soil quality at a rate proportional to y_t given a farmland. Recall that y_t is treated as the value of output given the assumption that price is given and constant over time. Thus, soil quality evolves according to:

$$\dot{Q}_t = \eta Q_t - \theta y_t + \omega I_t. \tag{23}$$

For simplicity, assume that each farmer works a given amount of time, which means that there is no labor-leisure choice.

An individual farmer takes the levels of environmental amenity associated with soil quality (A_t) and the shift factor of production function (Φ_t) as fixed (while a social planner does not take these as fixed), and maximizes (19) subject to the constraints (20), (21), (22), (23), the initial condition for soil quality and the transversality condition. The current value Hamiltonian associated with this maximization problem is given by:

$$H = u(c_t, \overline{A}_t) + \lambda_t[\eta Q_t - \theta\{\Phi_t Q_t^\beta - \gamma(1-\mu) I_t\} + \omega I_t] \tag{24}$$

where λ_t is he current shadow value of unit of soil quality. Note that before we derive first order conditions, it is necessary to express investment (I_t) as a function of consumption and soil quality. This can be done by rearranging equations (20) and (22). The Hamiltonian obtained after this substitution is presented in the appendix. In this optimal control problem, we have one control variable (c_t) and one state variable (Q_t).

According to the maximum principle, the optimal paths of c_t, Q_t, and λ_t satisfy the following first order and transversality conditions:

$$\frac{\partial u(\cdot)}{\partial c} = \lambda_t\left[\frac{\theta\gamma(1+\tau)}{1+\tau+\gamma} + \frac{\omega(1+\tau)}{(1-\mu)(1+\tau+\gamma)}\right], \tag{25}$$

$$\dot{\lambda}_t = \lambda_t\left[\left\{\theta - \frac{\gamma}{1+\tau+\gamma} - \frac{\omega}{(1-\mu)(1+\tau+\gamma)}\right\} f_Q - \eta + r\right], \tag{26}$$

$$\lambda_T = \frac{\partial(S(Q_T))}{\partial Q_T}, \tag{27}$$

where f_Q is the marginal productivity of soil quality given by $\beta\Phi_t Q_t^{\beta-1}$. Equation (26) describes the optimal path of the current shadow value of soil quality and equation (27) denotes the transversality condition. This transversality condition says that the current shadow value of soil quality at the terminal time should be equal to the value of marginal contribution of soil quality to land price at time T. Therefore, it is uneconomical for the farmer to deplete soil quality completely near the end of planning horizon. Combining equations (25) and (26), the maximization of the representative farmer's utility stream and the salvage value of the land in (19) implies that the growth rate of consumption at each time t is characterized by the following Euler equation:

$$g_c = \frac{\sigma}{1-\zeta+\sigma\zeta}\left[\left\{\frac{\gamma}{1+\tau+\gamma} + \frac{\omega}{(1-\mu)(1+\tau+\gamma)} - \theta\right\} f_Q + \eta - r\right]. \quad (28)$$

This Euler equation implies the following. First, the growth rate of consumption is positively related to the investment efficiency measure (ω), the investment subsidy (μ), the regeneration rate (η) and the intertemporal elasticity (σ). Second, the growth rate of consumption is negatively related to the income support measure (τ), the rate of soil degradation by intensive cultivation[11] (θ) and the discount rate (r).

These finding are all sensible and in particular the two different policy tools (investment subsidy and income support) have different implications for the growth rate of consumption in the steady state. Holding other things constant, it can be shown that while the investment subsidy favors the growth of consumption in the steady state, income support may not. This would confirm the belief that price support programs might result in excessive land use and hence reduce the rate of consumption growth in the long run. On the other hand, investment subsidy programs like CRP (Conservation Reserve Program) can raise the rate of consumption growth in the long run by providing more incentives to undertake soil-conserving investments.

The command optimum solution also highlights two features of the model. They are (i) the presence of positive marginal utility of soil quality and (ii) the higher level of marginal productivity of soil quality compared to DCE. Appropriate interpretations can also be made using the arguments in section 3.

[11] One modification that could be made concerns the determination of the depletion rate (θ) by the choice of technique. As discussed in Walker(1982), this soil depletion rate could capture the effects of another possible policy instrument; if a farmer decides to adopt a conservation tillage system, the rate of soil depletion might be reduced so that θ takes on a lower value than under a conventional tillage system. Thus, adoption of soil-conserving techniques can increase the rate of consumption growth in the steady state by reducing the rate of soil depletion. Therefore, it would seem that government programs for promoting the dissemination of information on the long-term effects of tillage system on soil conservation would be beneficial to a society in the long run.

In summary, the level of consumption under CO can grow faster than under DCE holding other parameters constant because a social planner can internalize the externalities associated with land degradation. Put differently, this simple model shows that economic growth (in agricultural sector) and soil quality can be complements rather than substitutes in the long run.[12)]

However, note that all of these findings depend on the degree to which soil-conserving investments can be capitalized into land prices, because the above Euler equation (28) ignores the transversality condition. What would be anticipated if land prices fail to capture soil quality differentials? Next, we will examine the effect of land market imperfections on investment and the effectiveness of government policies in terms of social welfare change.

4.2. The Effects of Land Market Performance on Soil-conserving Investments

The transversality condition requires that the shadow value of soil quality evolves over time, until in the last period the implicit value of soil quality just equals its marginal contribution on the land price. The discrete version of the analytical relationship between the shadow values of soil quality at time t and T is implied by equations (26) and (27):

$$\lambda_t=\left[\frac{1}{1+r-\eta+k\cdot f_Q}\right]^{T-t}\frac{\partial S(Q_T)}{\partial Q_T}, \tag{29}$$

$$k=\left(\theta-\frac{\gamma}{1+\tau+\gamma}-\frac{\omega}{(1-\mu)(1-\tau+\gamma)}\right).$$

Let scenario A denotes the case in which all market participants share the same information about soil quality (perfect information), and let scenario B indicates the case in which all market participants do not share the same information (asymmetric information). Since the shadow value of soil quality at time t and T should be on the same path, the value inside the bracket in (29) must be positive. According to (29), it is expected that the shadow value of soil quality at time t in scenario B to be less than that in scenario A because the value of the marginal contribution of soil quality to land price at time T in scenario B is less than in scenario A by construction. Since the shadow value of soil quality (implicit or user costs of soil quality) is low in B, we also expect a lower level of soil-conserving investments in scenario B.

The degree to which land market performance affects investment is also shown to be a function of the parameters in the system as in (29). One of the interesting parameters is the length of planning horizon (T). What would happen

[12] Following the same logic developed in the previous section, comparing the growth rate of consumption under CO and DCE yields: $g_c^{co}=g_c^{DCE}+\frac{\sigma}{1-\zeta+\sigma\zeta}\left[\left\{\frac{\gamma}{1+\tau+\gamma}+\frac{\omega}{(1-\mu)(1+\tau+\gamma)}-\theta\right\}\alpha\delta Q_t^{\alpha+\beta-1}+\omega\left(\frac{\zeta}{1-\zeta}\right)\left(\frac{c_t}{Q_t}\right)\right]$

if the planning horizon were short? Conventional wisdom suggests that a smaller T results in lower investment rates by truncating the flow of returns or investments that pay off over many years; investment should thus be an increasing function of T. To explore this, let us examine the derivative of λ_t in (29) with respect to the length of planning horizon (T). As shown in (30), the sign of this derivative depends on the sign of $\ln\left(\frac{1}{1+r-\eta+k\cdot f_Q}\right)$.

$$\frac{\partial\lambda_t}{\partial T}=\ln\left(\frac{1}{1+r-\eta+k\cdot f_Q}\right)\cdot\left[\frac{1}{1+r-\eta+k\cdot f_Q}\right]^{T-t}\frac{\partial S(Q_T)}{\partial Q_T}, \tag{30}$$

where $k=\left(\theta-\frac{r}{1+\tau+r}-\frac{\omega}{(1-\mu)(1+\tau+r)}\right)$

It is easy to see that if the sign of $\ln\left(\frac{1}{1+r-\eta+k\cdot f_Q}\right)$ is positive then λ_t decreases (increases) as T decreases (increases). This in turn reduces the shadow value of soil quality at time t, which results in underinvestment when the length of planning horizon is shorter. Now, under what conditions does this logarithmic value take a positive sign? The following inequality given by (31) is the necessary and sufficient condition:

$$\eta-r+\left(\frac{\omega}{(1-\mu)(1+\tau+r)}+\frac{r}{1+\tau+r}-\theta\right)\cdot f_Q>0. \tag{31}$$

The above condition is likely to be met when soil regeneration rate (η) and/or investment efficiency rate (ω) take bigger values. In this case, a longer planning horizon would result in an increase in investment because higher investment efficiency rate would likely increase the current shadow price of soil quality at time t when the length of planning horizon increases. However, this condition is likely to be violated when discount rate (r) and/or soil deterioration rate (θ) take bigger values. In this case, for example, an extremely higher discount rate could result in a decrease in investment due to the lower value of the current shadow price even when T increases. It is also noteworthy that if land markets are not perfect, then the degree to which underinvestment occurs tends to be more severe as T decreases.

4.3. The Effects of Income Support and Investment Subsidy Programs on Investment

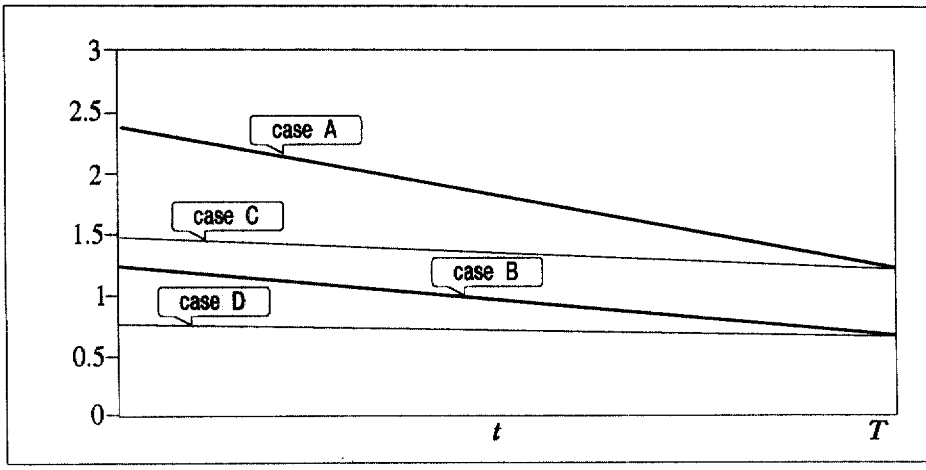
As already shown, income support and investment subsidy programs have different implications for the long-run growth rate of consumption. One possible explanation associated with these different policy outcomes may stem from the different impacts of two conflicting policies on farmers' decisions about soil conservation investments. It has been argued that price support programs may result in soil-depleting outcomes because they stimulate excessive use of soil (Burt 1981, McConnell 1983, Barbier and Bishop 1995, and Van Vuuren 1986). By contrast, direct subsidies for soil-conserving investments (e.g., CRP) could generate higher incentives to undertake such investments (Clarke 1992). To examine these arguments more thoroughly, let us examine the derivatives of λ_t in (29) with respect to the rate of investment subsidy (μ) and income support (τ). As shown in appendix (A-3, A-4), we find a positive relationship between the current shadow value of soil quality and μ. Since a higher shadow value implies higher incentives to undertake investment, this finding supports Clarke's argument. As expected, we also find a negative relationship between the current shadow value of soil quality and τ. This is again an intuitive result because a lower shadow value of soil quality undermines the conservation incentives. The derivatives also show that the degree to which investment subsidy and income support programs affect investment decisions depends on the size of λ_T. This clearly underscores the importance of land market performance in soil conservation outcomes because the operation of the land market determines the degree to which soil-conserving investments or soil-degrading decisions are reflected in land prices. If the land market does not perform well enough to capture the soil-conserving or soil-degrading effects of previous decisions, then land prices would undervalue returns to soil-conserving investments, thus reducing the effectiveness of investment subsidy programs. Imperfect operation of land market implied by the lower value of λ_T also promotes excessive use of soil and thereby increases the soil-degrading impact of price support programs.

4.4. Social Welfare Effects of Land Market Imperfection

This section explores the effects of land market imperfection on social welfare changes when an investment subsidy program is introduced. By making assumptions about the parameter values in (29), we can characterize implied paths of the current shadow value of soil quality as a function both of policy variables and λ_T. First, suppose that the discount rate is 0.03 and the rate of investment subsidy is equal to 0.5. For simplicity, also assume that when land markets are perfect, the marginal contribution of additional unit of soil quality to the salvage value is 1. Suppose also that this takes the value of 0.5 when land markets are imperfect. The discounted implicit cost paths (or current shadow values) of soil quality under the different set of conditions on land market performance are shown in Figure 1.

First, consider the case in which the same information about soil quality is available to both sellers and potential buyers. Given the first derivative of the salvage value of the land, the path of current shadow value with $\mu > 0$ is always above the path with $\mu = 0$, meaning that investment subsidy programs will increase the level of current shadow value of soil quality. These paths are

[Figure 1] The current shadow value paths of soil quality under different assumptions about land market operation when investment subsidy program is considered.



Case A = perfect information ($\mu>0$). Case B = asymmetric information ($\mu>0$).
Case C = perfect information ($\mu=0$). Case D = asymmetric information ($\mu=0$).

pictured using thick lines in Figure 1. Also, similar paths under asymmetric information about soil quality between market participants are pictured using thin lines. The area under the path of [perfect and $\mu>0$] and above the path of [perfect and $\mu=0$] can be regarded as the amount of total welfare increases associated with investment subsidy program, measured in terms of the current shadow value of soil quality. Note, however, that this is not a net welfare increase because the costs of implementing the investment subsidy are not considered. On the other hand, if land market are not perfect, then the total increase in welfare by introducing the program will be the area under the path of [asymmetric and $\mu>0$] and above the path of [asymmetric and $\mu=0$]. Therefore, the net welfare loss due to imperfect information in land market is equal to the differences between two areas. Although the size of welfare loss will depend on the parameter values used in the simulation, the implication of this model emphasizes the fact that a form of land market failure due to incomplete observability of soil quality will create another dimension of the soil degradation problem, i.e., a welfare implication.

V. SUMMARY AND CONCLUSIONS

The role of externalities in agricultural resource allocation has been well recognized. Yet a comprehensive framework to assess the impacts of agricultural resource allocation on the environment is not well developed. One potential reason is the difficulty of making links between agricultural land use decisions and their effects on environment. In this paper, we have used an endogenous growth approach to examine the effects of underlying externalities on an economy as a whole. As is well known, the endogenous growth approach is suitable for assessing the outcomes of economic behavior where externalities are present. The general model developed in this study extends the existing literature in this field not only by focusing on positive environmental externalities in terms of both consumption and production, but also by explicitly identifying environmental quality as a state variable. A social planner's problem is specified in such a way that she understands the full interactions between environmental quality and both production and utility. We show that given certain conditions, economic growth and environmental quality can be complements rather than substitutes.

In the soil conservation problem, the analytic results from command optimum indicate that if there exist some form of collective interventions designed to include both on-farm and off-farm costs in the cost structure, then society can be better off in terms of growth rates. It is noteworthy to stress two striking features of the model which bring about this intuitive result. First, soil quality is explicitly included in the model and in addition, it is endogenously determined by farmer's optimal behavior. The model also includes soil quality in the utility function, reflecting a recent development of the soil quality concept (environmental quality related). This consequently identifies the link between agricultural resource allocation and its impact on environment.

This specific model also pushes the research frontier in the area of on-farm market failures in several ways. First, although the model includes the salvage value of the land in the maximization problem as in McConnell(1983), this model takes further steps. One of the innovative aspects of the model is the fact that a land market imperfection is characterized as a function of the unobserved nature of soil quality, i.e., possible information gaps between sellers and potential buyers of land. By incorporating a potential land market imperfection into the maximization problem, this model formally provides an alternative and market-oriented framework for explaining farmers' underinvestment behavior without relying on a subjective discount rate story (McConnell(1983)).

Second, this model enables us to examine the effects of government programs on farmer behavior regarding soil conservation investment. It is shown that while price support programs have the effects of discouraging farmers from undertaking soil-conserving investments, and thus lead to excessive land use, investment subsidy programs increase farmers' incentives and hence contribute to the long-run growth of consumption. These policy effects depend on the performance of land markets. When land market information is not symmetrically shared, the beneficial effects of an investment subsidy program are shown to be less than those found in the case of a perfect land market. This is another source of costs that society may face if land market imperfections are not counteracted.

Third, in contrast with the McConnell model, the quality of the soil is not fixed in this model and can be improved by measure of soil-conserving investments. Thus, as argued by Clarke, the important role of soil quality adjustment dynamics is not assumed away through assuming a constant soil quality land.

Combined, our model reveals a new aspect of the land degradation issue, namely the relationship between asymmetry of information on soil quality and the functioning of land market. In particular, it motivates an extension of the Akerlof(1970) model in which the quality of goods (unknown to potential buyers) evolves dynamically over time, thus generating a form of market failure in resource allocation problems.

APPENDIX

1. The Derivation of Hamiltonian

Rearrange (20) and (22) to express I_t as c_t and Q_t:

$$(1-\mu)I_t = \frac{\Phi_t Q_t^\beta}{1+\tau+r} - \frac{(1+\tau)c_t}{1+\tau+r}. \tag{A-1}$$

The current value Hamiltonian after substituting I_t using (A-1) is given by:

$$H = U(c_t, \bar{A}_t) + \lambda_t \left[\begin{array}{l} \eta Q_t - \theta\left\{ \Phi_t Q_t^\beta - \dfrac{r\Phi_t Q_t^\beta}{1+\tau+r} + \dfrac{r(1+\tau)}{1+\tau+r} c_t \right\} + \\ \omega\left\{ \dfrac{\Phi_t Q_t^\beta}{(1-\mu)(1+\tau+r)} - \dfrac{r(1+\tau)}{(1-\mu)(1+\tau+r)} c_t \right\} \end{array} \right]. \tag{A-2}$$

2. Finding the Relationship between Policy Parameters and the Current Shadow Value of Soil Quality

Taking the first derivative of the RHS of (29) with respect to μ and τ respectively yields:

$$\frac{\partial \lambda_t}{\partial \mu} = (T-t)\left[\frac{1}{1+r-\eta+k\cdot f_Q}\right]^{T-t-1} \frac{\partial S(Q_T)}{\partial Q_T} \left[\frac{\dfrac{\omega(1+\tau+r)f_Q}{\{(1+\tau+r)(1-\mu)\}^2} - k\cdot \dfrac{\partial f_Q}{\partial \mu}}{(1+r-\eta+k\cdot f_Q)^2} \right] > 0, \tag{A-3}$$

and

$$\frac{\partial \lambda_t}{\partial \tau} = (T-t)\left[\frac{1}{1+r-\eta+k\cdot f_Q}\right]^{T-t-1} \frac{\partial S(Q_T)}{\partial Q_T} \left[\frac{-\left[\dfrac{r}{(1+\tau+r)^2} + \dfrac{\omega(1-\mu)f_Q}{\{(1+\tau+r)(1-\mu)\}^2}\right]}{(1+r-\eta+k\cdot f_Q)^2} \right] < 0, \tag{A-4}$$

where $k = \left(\theta - \dfrac{r}{1+\tau+r} - \dfrac{\omega}{(1-\mu)(1+\tau+r)}\right)$.

The sign of (A-3) is shown to be positive when $T > t$ since $\omega > 0$, $\frac{\partial f_Q}{\partial \mu} > 0$ and $k < 0$ (this is because $\frac{\partial \lambda_t}{\partial f_Q} > 0$). The sign of (A-4) is negative when $t < T$ since $\omega > 0$.

REFERENCES

Agricultural Outlook. *Agricultural Outlook.* U.S. Department of Agriculture, Economic Research Service, Agricultural Economic Report No. 606 September, 1995.

Akerlof, G. "The market for lemons: Quality uncertainty and the market mechanism," *Quarterly Journal of Economics* 89, 1970, pp. 488-500.

Ayers, Robert U. "Optimal Investment Policies with Exhaustible Resources: An Information-Based Model," *Journal of Environmental Economics and Management,* Vol. 15, 1988, pp. 439-461.

Barbier, E.B. "The Farm-Level Economics of Soil Conservation: The Uplands of Java," *Land Economics* 66(2), 1990, May, pp. 198-211.

Barbier, E.B., and J.T. Bishop. "Economic Values and Incentives Affecting Soil and Water Conservation in Developing Countries," *Journal of Soil and Water Conservation,* March-April, 1995, pp. 133-137.

Barro, Robert. "Governmental Spending in a Simple Model of Endogenous Growth," *Journal of Political Economy,* 1990, pp. 103-125.

Burt, O. "Farm Level Economics of Soil Conservation in the Palouse Area of the Northwest," *American Journal of Agricultural Economics* 63, 1981, pp. 83-91

Clarke, H.R. "The Supply of Non-degraded Agricultural Land," *Australian Journal of Agricultural Economics* 36(1), April, 1992, pp. 31-56.

Coxhead, I. "Modelling the Economics of Agricultural Land Degradation," Dept. of Agricultural and Applied Economics, Univ. of Wisconsin-Madison, Staff Paper Series No 385, 1995.

Elbasha, E.H. and T. Roe. "On Endogenous Growth: The Implications on Environmental Externalities," Economic Development Center, University of Minnesota, 1995.

Gardner, K. and Richard Barrows. "The Impact of Soil Conservation Investment on Land Prices," *American Journal of Agricultural Economics* 67, 1985, pp. 943-947.

Kim, Kwansoo, Bradford L. Barham, and Ian Coxhead. "The evolution of agricultural soil quality:A methodology for measurement and some land market implications," Dept. of Agricultural and Applied Economics, Univ. of Wisconsin-Madison, Staff Paper Series No 413, 1997.

Krautkraemer, J. "Optimal Growth, Resource Amenities and the Preservation of Natural Environments," *Review of Economic Studies,* Vol. 52, 1985, pp. 153-170.

LaFrance, J.T. "Do Increased Commodity Prices Lead to More or Less Soil Degradation?" *Australian Journal of Agricultural Economics* 36(1), April 1992, pp. 57-82.

Ligthart, Jenny E., Frederick van der Ploeg. "Pollution, the cost of public funds and endogenous growth," *Economics Letters* 46, 1994, pp. 351-361.

Lucas, Robert. "On the Mechanics of Economic Development," *Journal of Monetary Economics,* 1988, pp. 3-42.

McConnell, K. "An Economic Model of Soil Conservation," *American Journal of Agricultural Economics* 65, 1983. pp. 83-89.

Mohtadi, Hamid and Terry Roe. "Endogenous Growth, Health and the Environment," Economic Development Center Bulletin Number 92-4, Univ. of Minnesota, July, 1992.

Ribaudo, Marc.O. "Reducing Soil Erosion: Offsite Benefits," Washington, DC: U.S. Dep. of Agriculture, Economic Research Service, Natural Resource Economic Division, Agricultural Economic Report No. 561, 1986.

Romer, Paul. "Endogenous Technical Change," Journal of Political Economy, 1990, s71-s102.

Smith, Vernon L. "Control Theory Applied to Natural and Environmental Resources: An Exposition," *Journal of Environmental Economics and Management,* Vol. 4: 1977, pp. 1-24.

Van Vuuren, W. "Soil Erosion: The Case for Market Intervention," *Canadian Journal of Agricultural Economics,* 1986, pp. 41-62.

Walker, D.J. "A Damage Function to Evaluate Erosion Control Economics," *American Journal of Agricultural Economics* 64, 1982: pp. 690-698.