The Science of the Total Environment, 55 (1986) 101—110
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

DESERTIFICATION FROM AN ECONOMIC PERSPECTIVE

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I want to thank Don Peterson, Payson Sheets, and Gilbert White for their helpful suggestions.

ABSTRACT

It is often asserted that desertification is a socially nonoptimal land use policy and that sustainable use is optimal. This paper analyzes this contention by developing a model that examines the optimal rate of desertification from the producer's perspective and from society's perspective. The results indicate that sustainable use is not necessarily optimal and that in some cases it might be optimal to completely desertify the land. Critical economic determinants of optimal land use policy are land-tenure arrangements, discount rates, and whether the selling price of the land at the end of the time horizon is a function of the soil's quality.

I. INTRODUCTION

This paper examines the relationship between man and the environment in the context of desertification. Desertification is a process that adversely affects man, but one to which man also contributes. A simple control model is developed to isolate those economic factors that make desertification more or less likely and to clarify how different land-tenure arrangements affect the rate of desertification.

Semi-arid lands can be viewed as a scarce resource that should be optimally allocated over time. They are a renewable resource that, like all other renewable resources, can be harvested, and if the harvest rate is sufficiently large, will be driven to extinction. The land can be utilized at some sustainable rate, but if the land is utilized more intensively, soil quality will deteriorate (desertification will take place). Alternatively, if the land's natural rate of regeneration is greater than the rate at which its quality is being harvested, quality increases. Complete desertification occurs when the agricultural potential of the land is irreversibly destroyed; i.e. driven to extinction.

The Sahel is a primary example of a part of the world that is experiencing extensive desertification (it "appears" as if the Sahara desert is marching southward), but the process is widespread. Many of the areas affected are in less developed countries, but parts of Australia and the United States are also

0048-9697/86/$03.50

affected. From an economic perspective, deforestation is effectively equivalent to desertification. Deforestation is also widespread, including extensive areas of Tibet and parts of the Amazon basin.

Everyone agrees that, ceteris paribus, desertification is undesirable but much of the desertification literature also suggests that desertification is nonoptimal from both the producer's and society's perspective. Sustainable use is generally put forward as the optimal strategy. Glantz and Orlovsky (1983), for example, state that, "man-induced extensions of these deserts or the creation of desert-like conditions in areas where they had not existed can and must be avoided." The U.N. Conference documents (1977) seem to consider all man-induced desertification to be due to factors such as ignorance, lack of foresight, government mismanagement and the "inability to apply existing knowledge."

The intent of this paper is to evaluate these contentions by developing a full-information certainty model that examines the optimal rate of desertification from the producer's perspective and from society's perspective. The model is designed to capture the important economic components of the problem rather than as an accurate mechanistic description of desertification. Certainty and full-information are assumed to demonstrate that "ignorance" and "lack of foresight" are not necessary conditions for desertification. The model considers how the rate of desertification is affected by land-tenure arrangements (private property, rental, corporate and common property) and those factors that will cause what is optimal from the producer's perspective to diverge from, or coincide with, what is socially optimal. The results indicate that sustainable use is not necessarily optimal and that in some cases it might be optimal to completely desertify the land. Critical factors include land-tenure arrangements, the discount rate, the initial quality of the soil and whether the value of the land at the end of the time horizon is a function of the soil's quality.[2] A zero discount rate is a necessary, but not sufficient, condition for the optimality of sustainable use.

Intuitively, it is only optimal to reduce the current rate of desertification if the marginal benefits of the reduction exceed the marginal costs. Considering, for example, the Sahel, the benefits of decreasing the rate of desertification are, in part, increased future food production; the costs are, in

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[2] The discount rate is a measure of the economic agent's rate of time preference. Your personal rate of discount indicates the rate at which you are willing to substitute future for current consumption. A zero discount rate indicates that all periods are weighted equally. As the discount rate increases, the present value of future net benefits declines. A discount rate of infinity indicates that the present value of any future net benefits is zero. The paper will draw a distinction between the producer's personal rate of discount, the social rate of discount, and the market rate of interest which is the rate at which the market allows one to substitute future for current consumption.

part, decreased current food production.[3] If the present value of the benefits of reducing desertification are less than the current costs, then it is obviously not optimal to reduce the rate of desertification. In the case of the Sahel, the costs may be too high.

II. THE MODEL

The basic model is adapted from McConnell (1983) who used it to model soil erosion. It is presented here, in modified form, as an explanation of desertification.

Assume that the production function for the output of the "agricultural" process is

$$x(t) = f(q(t), E(t)) \tag{1}$$

where $x(t)$ is output at time t, $q(t)$ is the amount of soil quality allocated to production at time t and $E(t)$ is the amount of effort allocated to production at time t. The production function identifies maximum output as a function of the input levels. The production process can be farming, ranching, nomadic pastoralism, or just primitive gathering. Assume that both inputs are essential and that $f_q \geq 0$, $f_{qq} \leq 0$, $f_E \geq 0$, and $f_{EE} \leq 0$ where f_q and f_{qq} (f_E and f_{EE}) are the first and second-order partial derivatives of the production function with respect to soil quality (effort). The derivatives f_q and F_E are the marginal products of soil quality and effort, respectively. The prices of $x(t)$ and $E(t)$, p and w, are assumed constant and parametric. Soil quality changes over time due to natural growth and agricultural production.

If $Q(t)>0$,

$$\mathring{Q}(t) \equiv dQ/dt = k - q(t) \tag{2}$$

where $Q(t)$ is the quality of the soil at time t, and where it is simplistically assumed that natural growth adds a constant amount of soil quality, k, in each period. If $Q(t)=0$, $\mathring{Q}(t)=0$. Sustainable use ($q(t)=k$) also implies that $\mathring{Q}(t)=0$. If $\mathring{Q}(t)<0$, desertification is taking place. If $Q(t) = 0$, the land has been completely desertified (i.e., irreversibly become agriculturally nonproductive). Complete the model by assuming that, Q_0 is the initial level of soil quality, the producer has a finite time horizon that terminates at time T, r is the producer's discount rate (note that r equals the market rate of interest if the

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[3] The model presented concentrates on food production, but the decision maker must also consider all the other benefits and costs associated with decreased desertification.

capital market is efficient)[4] and

$$S = S[Q(T)] \tag{3}$$

where S is the selling price of the land at T. Assume that $S_Q \geq 0$ and $S_{QQ} \leq 0$. An important special case is when the selling price of the land at T is independent of the quality of its soil at T (e.g., if the land is destined to be urbanized).

The producer's problem is, therefore, to find those paths of E(t), q(t) and Q(t) through time that maximize the present value of the production plan subject to the constraints

$$\underset{\substack{\text{wrt} \\ q(t),\ E(t),\ Q(t)}}{\text{MAX}} \ \text{Present Value} = \int_0^T e^{-rt} \, [\, pf(q(t), E(t)) - wE(t)] \, dt + e^{-rT} S[Q(T)] \tag{4}$$

$$\text{subject to } Q(0) = Q_0 \text{ and } \overset{\circ}{Q}(t) = k - q(t)$$

The present value of production plan consists of the present value of the output stream and the present value of the land's selling price at T. The necessary conditions for the optimal paths of E(t), q(t), and Q(t) are obtained as a special case of the Pontryagin maximum principle (see Arrow (1968). Intuitively, these conditions imply that, for every t, effort, E(t), should be utilized up to the point where the value of its marginal product, pf_E, equals its price, w, and soil quality should be used up to the point where the value of its marginal product, pf_q, equals its implicit price, $\lambda^*(t)$. That implicit price, $\lambda^*(t)$, is the marginal value of soil quality at time t; i.e., the reduction in the value of future profits caused by the use of one more unit of soil quality in period t ($\lambda^*(t) = e^{rt} \partial PV^* / \partial Q(t)$). The price of soil quality is "implicit" rather than a market price, because units of soil quality are not directly bought and sold in the market place. Along its optimal path, the implicit price of soil quality increases at the market rate of interst, r, and its terminal value, $\lambda^*(T)$, equals the sensitivity of the land's selling price at T to a marginal change in its soil quality at T, $\partial S[Q(T)]/\partial Q$. If the implicit price of the soil's quality is appreciating at a faster (slower) rate, $\overset{\circ}{\lambda}{}^*(T)/\lambda^*(t)$, than the average rate of return on other assets, r, then the producer should invest more (less) in soil quality by reducing (increasing) q(t). Maximizing the present value of the production plan is equivalent to maximizing the

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[4] The capital market is the market in which the interest rate is determined by the supply and demand for loanable funds. If this market is efficient, everyone will face the same parametric market rate of interest and each individual will allocate their consumption over time so as to equate their personal rate of discount and the market rate of interest.

present value of a portfolio that consists of two assets; soil quality and an index of other assets that appreciate at the market rate of interest. A necessary condition for the maximization of the present value of any portfolio is that all assets in the portfolio are appreciating at the same rate. If $\lambda^*(T) \neq \partial S[Q(T)]/\partial Q(T)$, the producer did not correctly account for the impact of soil quality on the selling price of the land.

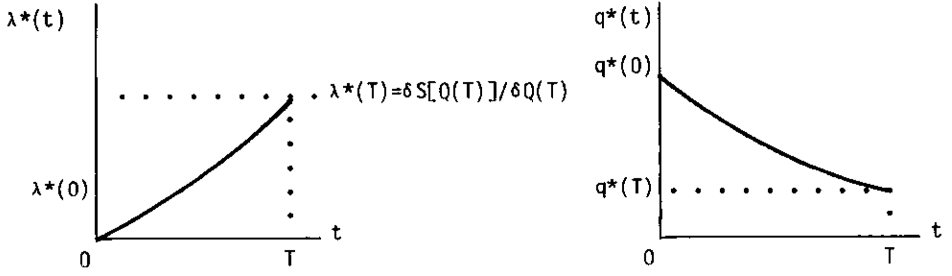
III. THE OPTIMAL RATE OF DESERTIFICATION FROM THE INDIVIDUAL PRODUCER'S PERSPECTIVE

The necessary conditions for the optimal paths of $E(t)$, $q(t)$, $Q(t)$, and $\lambda(t)$ can be used to determine the optimal rate of desertification as a function of the discount rate and the sensitivity of the land's sale price at T to its soil quality at T. Section III.A considers desertification assuming that the selling price of the land at T is an increasing function of its soil quality and section III.B considers the case where the land's selling price is independent of its soil quality.

III.A <u>Assume the land's selling price at T, S(T), is an increasing function of Q(T)</u>

Assuming that the production function, equation 1, is strictly concave, the necessary conditions for the optimal paths can be used to determine that if the discount rate is positive, the implicit price of soil quality, $\lambda^*(t)$, will increase at the market rate of interest, r, and that the optimal rate of soil quality reduction, $q^*(t)$, declines over time.[5] Optimal soil quality reduction, $q^*(t)$, is inversely related to its implicit price, $\lambda^*(t)$, because optimality requires that $q(t)$ be utilized in each period until the value of its marginal product equals its implicit price. Graphically, this might appear as follows:

Assuming $r > 0$



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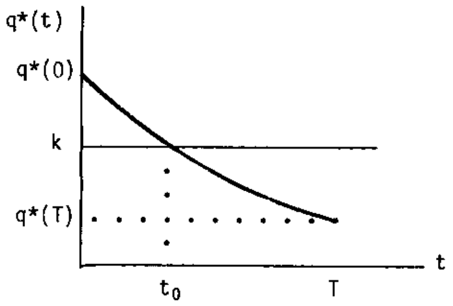
[5] The necessary conditions for optimality imply that $\dot{q}^*(t)=rf^*_q f^*_{EE}/(f^*_{qq}f^*_{EE} - f^*_{qE}{}^2)$. Strict concavity of the production function implies that $f^*_q>0$, $f^*_{EE}<0$ and that $(f^*_{qq}f^*_{EE} - f^*_{qE}{}^2)>0$. Strict concavity implies that the marginal products are strictly positive but declining. Many, but not all, production functions are strictly concave.

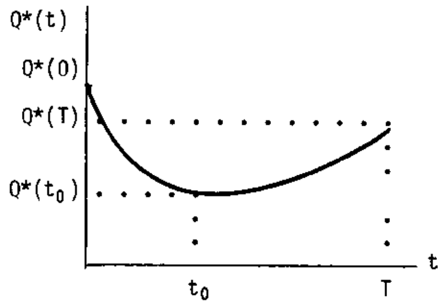
If the problem is solved for a larger r, $\lambda^*(0)$ is lower and $q^*(0)$ is larger, but the implicit price (rate of soil quality reduction) increases (declines) at a faster rate. A higher discount rate therefore causes the producer to use more soil quality in the initial periods, but the amount he uses declines more quickly causing him to possibly use less in later periods.

If the producer does not discount the future ($r=0$), the implicit price of soil quality, $\lambda^*(t)$, and the amount of soil quality used in each period, $q^*(t)$, are both constant. The producer uses the same amount in each period because the present value of a dollar's worth of profits does not depend on when those profits are earned. If the producer completely discounts the future ($r=\infty$), the implicit price of soil quality, $\lambda^*(t)$, is zero for all t. When more soil quality is used today, there is a decrease in future profits, but when the discount rate is ∞, the present value of that decrease is zero.

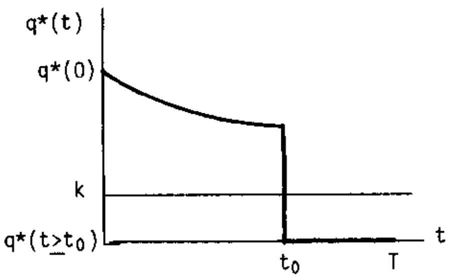
The optimal rate of desertification is determined by comparing the path of $q^*(t)$ with the soil's rate of regeneration, k. If $q^*(t)=k$ for all t, then sustainable use is optimal ($\overset{\circ}{Q}^*(t)=0$ for all t). Since $q^*(t)=k$ for all t implies that $\overset{\circ}{q}^*(t)=0$ for all t, a zero discount is a necessary, but not sufficient, condition for the optimality of sustainable use.

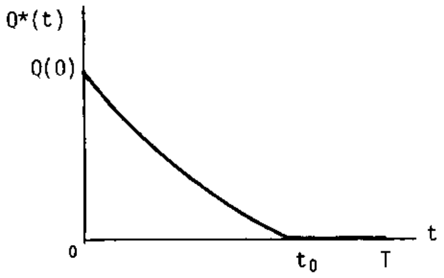
If $q^*(t)>k$, then it is optimal to desertify at t. For example, if the discount rate is positive, the optimal paths of q(t) and Q(t) might be as follows





Desertification is optimal until t_0, but the optimal level of soil quality increases after t_0. However, if k is sufficiently small relative to r, it might be optimal to desertify over the entire time horizon. In fact, it could be optimal to completely desertify the land at t_0, where $0\le t_0\le T$. Graphically this case is as follows on the next page. Factors that would make optimal extinction more likely are a high r and p, a low w, k and Q_0, and if the land's selling price at T is fairly insensitive to its soil quality. This is not to suggest that it is necessarily optimal for the producer to completely desertify the land but rather to suggest that it might be optimal if certain conditions prevail.





Complete desertification in the first period is definitely optimal if the producer completely discounts the future ($r=\infty$) and if the marginal product of q is positive for all q. In this case, the producer's maximization problem, (equation 4), simplifies to maximizing profits in the initial period. The producer will therefore completely desertify the land in the initial period unless the marginal product of q(0) becomes nonpositive before Q_0 is depleted.

III.B Assume the land's selling price at T, S(T), is independent of Q(T)

Often the selling price of the land at time T is independent of its soil quality at T (e.g., it is destined to be urbanized). Knowledge of this will cause the producer to completely desertify the land if the marginal product of q is positive but declining for all q. There is no incentive to conserve soil quality in the terminal period T. If the produer's discount rate, r, is zero, then soil quality will be reduced by an equal amount in each period ($q^*(t)=q^*$) such that the land is completely desertified in period T. If the discount rate is positive, complete desertification can come sooner. The only thing that will make complete desertification nonoptimal in the case where the land's selling price is independent of its soil quality is if the marginal product of soil quality becomes nonpositive at a sufficiently small level of q relative to Q_0 and k.

IV. THE IMPACT OF DIFFERENT LAND TENURE ARRANGEMENTS ON THE PRODUCER'S OPTIMAL RATE OF DESERTIFICATION

The results outlined in the previous section can be used to analyze the producer's optimal rate of desertification under four different land-tenure arrangements: the privately owned family "farm" (T is the retirement age of the farmer and $\partial S[Q(T)]/\partial Q(T) \geq 0$); the rented family farm (T is the same, but the renter receives none of the proceeds from the sale of the land); the corporate producer (an infinite time horizon); and the common property situation.

IV.A Comparing the corporate structure with the privately owned family farm

It is often suggested in the desertification literature that large corporate farms (ranches) desertify at a faster rate than privately owned farms (see, for example, United Nations Conference on Desertification (1977)). This is not true if the capital market is efficient, both parties have the same information and neither party has any monopoly power. If all three conditions hold, the selling price of the land at time T will equal its maximum present value at time T from both the farmer's and corporation's perspective and the family farmer and corporation will behave identically. The corporate structure is not inherently more prone to cause desertification than the individual farmer.

If they desertify at different rates, it is because one of the above three conditions is violated. A typical scenario might be that the borrowing rate for the family farmer is greater than the corporate rate (an inefficent capital market), and if either one has market power, it is the corporation and not the family farmer. These two factors will cause the corporation to conserve more, rather than less soil quality. The positive rates of desertification that we observe on large corporate ranches and farms in the United States and Australia are not necessarily suboptimal from the corporate owners' perspective, and transferring these ranches and farms to family ownership will not necessarily decrease the rate of desertification.

IV.B Renters

The farmer who rents will choose a rate of desertification that completely desertifies the land by period T. A farmer that owns the land will desertify at the same rate if the lands selling price at T is not a function of its quality but at a slower rate if it is. The critical difference is that the renter ignores the effect of his actions on the sale price of the land. The owner considers the value of the land at T because he plans to either sell it or bequeath it. Ownership, be it family, corporate, or even government, encourages conservation of the soil's quality, but the owner might still find it optimal to deplete the soil's quality.

IV.C Common property

Much of the land in less developed countries that is being desertified is common property. Examples abound and include parts of the Sahel, the Amazon basin, and Tibet. Access to common property land is not controlled so producers who utilize it behave as if their discount rate is ∞. They behave this way not because they do not care about the future but because their current rate of soil use will have no impact on the level of soil quality in the future; if one producer attempts to conserve by reducing his use of the soil's quality, another producer will harvest it instead. Each producer, therefore, maximizes their short run profits from the land by utilizing soil quality until its marginal product is zero. As section III.A shows, rapid and complete desertification is likely. This result seems to be contradicted by the fact that nomadic pastoralists have lived for centuries more or less in balance with their common property environment. However, in the past, population pressure was not sufficient to drive these common property renewable resources to extinction. Disease kept the population size in check. Modern health care and veterinary medicine has eliminated that check.

V. THE SOCIALLY OPTIMAL RATE OF DESERTIFICATION

The socially optimal rate of desertification equals the optimal rate from the producer's perspective (corporate or private owner) if the producer's discount rate, r, equals the social rate of discount, δ, if market prices, p and w, reflect social values, and if $S[Q(T)]$ reflects the social value of the land at T. Ceteris paribus, as δ increases, the socially optimal rate of desertification increases. The socially optimal rate of desertification is also critically dependent on whether the social value of the land at T is an increasing function of its soil quality. If it is not, it will be socially optimal to completely desertify the land by T. If it is, the socially optimal rate of desertification will depend on δ.

Many philosophers and economists have eloquently argued that the social rate of discount should be zero (see, for example, Solow (1974). If it is zero, and if the social value of the land at T is a function of its soil quality, sustainable use is likely to be socially optimal. Since producers discount the future ($r>0$), the actual rate of desertification will be too high and the market will fail. If desertification produces negative externalities (e.g., if desertifying one piece of land negatively impacts the regenerative capacity of adjacent lands), private owners will also desertify too quickly.

However, one might just as effectively argue that societies near subsistence might appropriately have large discount rates. In which case, the common property rate of desertification might be close to socially optimal. For example, we can't say on theoretical grounds that the current rate of desertification in the Sahel is socially nonoptimal. The cost of reducing the rate might be too high.

Man's impact on desertification is important and is not completely attributable to ignorance, the lack of foresight and government mismanagement. Land-tenure arrangements, discount rates, and whether the terminal value of the land is a function of its soil quality are all important.

VI. EXTENSIONS

While instructive, the simple model presented ignores a number of the important components of the problem. People in arid regions are subjected to major random fluctuations in climatic conditions (droughts). The producer's reaction to these fluctuations is complicated by the fact that even in areas where the land is a common property resource, the producer can invest in grazing animals. One of the capital goods is owned and the other is not. There will be overinvestment in animals from society's perspective, and this overinvestment will be exacerbated by the climatic fluctuations. A large herd is the producer's only available insurance policy against drought. Producers will save for the future in nondrought periods by investing in animals and then try to maintain those animals for as long as possible after the drought begins. While this behavior is optimal from the private producer's perspective,it is not socially optimal and will contribute significantly to desertification.

While it is reasonable to assume that agricultural prices are parametric for most producers, it is not reasonable to assume that they are parametric from society's perspective if agricultural prices are determined in internal markets. In this situation, producers know that agricultural prices will rise as desertification proceeds and will take this into account by reducing their current rate of desertification so that they will be able to sell more later at those higher prices. The optimal social rate of desertification is also lower at each point in time if food prices in the country rise due to desertification. If prices are endogenous, the process is best modelled from society's perspective by specifying a social welfare function which is a function of percapita food production. Society's optimal rate of desertification will be critically dependent on the form of that function.

Population size is also an important endogenous variable. Land tenure and other institutional arrangements that were consistent with sustainable land use in many areas for hundreds of years when the population was kept in check by disease and infant mortality are now contributing to the high rate of desertification in those same areas. Population size can increase substantially in nondrought periods only to decrease drastically during the drought. The Sahelian drought of 1968-73 resulted in more than 100,000 human deaths and a loss of up to 12 million cattle (Glantz (1980)). Population size depends on soil quality but also is an important determinant of the level of soil quality in future periods.

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