Exploring long-term land improvements under land tenure insecurity

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Summary

This article explores long-term land improvement (lime application) under land tenure insecurity on leased land. The dynamic optimisation problem is solved by a stochastic dynamic programming routine with known parameters for one-period returns and transition equations. The model parameters represent Finnish soil quality and production conditions. The farmer's decision rules are solved for alternative likelihood scenarios over the continuation of the fixed term lease contract. The results suggest that, as the probability for non-renewal of the lease contract increases, farmers quickly decrease investments in irreversible land improvement and, thereafter, yields decline gradually. The estimated decision rules are a part of larger set of farmer's decision rules to be taken care when land leasing and environmental legislation is renewed.

Key Words

Dynamic programming, land tenure, land improvements

Introduction

The soils of Finland have been formed from acidic rock and *pH* values in agricultural soils in the country are commonly below the recommended level. Therefore, liming is one of the basic ameliorative measures used to maintain good yields. There used to be a slight but steady gradual increase of soil *pH* from the 1960's until the 1990's, but particularly during the last decade liming has been practiced far less than recommended. At the same time structural development has, in turn, gradually shifted cultivated land from land owners to tenants. Over the years 1974–2003, the share of land cultivated under lease contracts by tenants increased from 4.8% to 33.0%, *i.e.* by 28.2 percentage points.

The standard land lease contract in Finland is a short term contract with fixed duration and a fixed cash lease payment per year. About 38% of all lease contracts have a duration of five years. With only few exceptions, the annual cash lease payment is fixed per hectare of land when the contract is signed. Contracts longer than 10 years are forbidden by law (Maanvuokralaki 08.10.2003).

Tradition in empirical studies

It is argued that well-developed institutional arrangements and efficient asset markets should solve problems caused by land tenure insecurity (McConnell 1983). Hence, economic literature analysing the implications of land tenure insecurity focuses for the most part on developing countries where asset markets likely exhibit inefficiencies (Sjaastad and Bromley 1997; Li *et al.* 1998; Deininger 2003). In these countries, land tenure insecurity has large implications, not only on land improvements, but also on household and society welfare. Even if the problems caused by land tenure insecurity are apparent, empirical studies have not, however, been able to strongly identify and characterise their effects. The data have not been informative enough, because in developing countries household access to farming inputs and markets can be severely restricted by institutional, financial, and economic factors as well as by land tenure insecurity. Thus, it has been difficult to isolate the land insecurity impact in statistical testing (Holden and Hailu 2002).

Upcoming problem

In richer countries, land tenure insecurity has not received much attention in the economic literature. Even if land tenure insecurity is not yet a dominating problem in these countries, it may become such, particularly in Less Favoured Areas (LFA), where production costs are high and yields are low. The trend towards a more liberalised food market and internationally harmonised agricultural policies decrease Marginal Value Products (MVP) for agricultural inputs in LFA areas where farmer options to adjust to these trends are limited. Because the pay-back periods of irreversible land improvements get longer, we may expect that in the LFA areas of northern Europe land improvements may decrease below the socially optimal levels if farmers are confronted with significant land tenure insecurity.

The decreased MVP cannot alone explain the decrease in land improvements, but it is expected to strengthen the implications related to land tenure insecurity, because tenants, in particular, may no longer have the incentives to make land improvements in Finnish conditions as they had in the past.

Tool for policymakers

This article is to highlight the problem by solving and characterising the optimal decision rules to invest in long-term land improvements conditional on land tenure insecurity. Farmers’ optimal decision of liming is examined at the parcel level. The economic dynamic optimisation model is numerically solved by dynamic programming with known parameters for one-period returns and transition equations. The decision rules are solved conditional on alternative scenarios on the likelihood that the lease contract expires. The model parameters represent Finnish conditions and are based on field experiments. The results suggest that optimal land improvements decrease quickly as the uncertainty over contract renewal increases and, thereafter, the yields decline gradually. Results confirm that farmer's decision rules have to be taken care, when laws concerning environmental restrictions, land leasing and farmers access to the farmland are renewed.

The model

The Land Tenure Insecurity Problem

The farmer's problem is to optimise lime applications in a dynamic context under certain carry-over effects. The optimisation problem is normalised to one hectare of leased land and the crop used is spring barley. It is the most common cereal grown in Finland.

The model represents land that has sufficient quality so that the long-run equilibrium is to keep the soil *pH* status at satisfactory[1] levels from a society perspective, *i.e.* without distortions caused by land tenure insecurity. In more marginal land areas, the land tenure insecurity problem is not the only institutional factor that is decreasing irreversible soil improvements in a high cost country with a sparse rural population, such as occurs in Finland.

The implication of land tenure insecurity was modelled through a sequence of fixed duration (τ) land leasing contracts. We simulated a five-year ($\tau=5$) cash lease contract, which is the standard duration for lease contracts in Finland. The average duration of lease contracts in Finland is six years and 38% of all lease contracts have a duration of five years (Myyrä 2004). Five-year contracts and commitments are often required in agri-environmental programmes. Contracts longer than 10 years are forbidden by law (Maanvuokralaki 08.10.2003). The most common lease payment is a fixed cash payment which is agreed when the contract is signed. Under this contract design, short-term land rent can be maximised simply by leasing the land for a farmer who pays the highest cash lease.

The farmer has sure access to the land, until the contract's next expiration date $t=n\tau$, for $n=1,2,3,\ldots,20$. At each renewal date $t=n\tau$, the renewal of the contract is risky with an exogenous probability $Prob_{n\tau}$. Because continuation and expiry are mutually exclusive, the probability that the lease contract expires is ($1-Prob_{n\tau}$) and, once the contract expires, the one-period returns are assumed to stay at zero forever. Thus, the expiry is assumed irreversible.

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[1] The values of *pH* status are divided into seven classes as follows: poor, rather poor, fair, satisfactory, good, high and excessive (Viljavuuspalvelu Oy – Soil Analysis Service Ltd. 2000). The class limits are based on an extensive number of field experiments. Satisfactory is the target class, considered sufficient for normal yields of field crops such as cereals and ley. Soil *pH* is determined in water suspension.

The Bellman equation

The optimisation problem is formalised as a recursive finite horizon (T) dynamic programming problem that is solved numerically by iterating the Bellman's equation (Bellman 1957):

$$V_t(z_t) = \max_{u_t} \left\{ R_t(z_t, u_t) + \beta Prob_t \left[V_{t+1}(z_{t+1}) \right] \right\}, \quad t = 0,1,\ldots,T \tag{1}$$

$$\text{subject to} \quad z_{t+1} = \mathrm{g}(z_t, u_t)$$

$$z_t \text{ given}, \; T=100$$

$$\textit{where } 0 \le Prob_t \le 1 \text{ for all } t = n\tau, \text{ and } Prob_t = 1 \text{ otherwise.}$$

where the optimal value function (V_t) is the function of the current state vector (z_t); u_t is the control (also called the decision rule or policy function); $R_t(.)$ is the one-period net return function; β is the discount factor. The optimal value function is constrained by transition equations, in which $g(.)$ is a function. It determines the connection between the current state and control and the next period state. The optimal solution is a function of the initial state z_t. This specification generalises the models presented in Kennedy (1986).

The one-period net return (R_t) is the difference between the one-period revenue from selling the yield minus the expenditure of purchasing the control. Because other factors are held as fixed in the analysis, they can be suppressed and the one-period return function is:

$$R_t(z_t, u_t) = p_t y(x_t, u_t) - w_t u_t \tag{2}$$

where $y(x_t, u_t)$ is a deterministic yield response function, specified separately for phosphorus and lime (see below). The last term $w_t u_t$ is the expenditure on inputs, *i.e.* lime and phosphorus fertiliser.

The time horizon (T) was set at 100 years which guaranteed that not only the decision rules but also the stock variables and the value functions converged. The state vector (z_t) consists of the *pH* (x_t) and the output prices (p_t) as well as the price of the control variable (w_t). Prices are assumed deterministic such that the current prices prevail in the future. Thus, the transition equations for prices are simply

$$p_t = p_{t+1} = \overline{p} \quad \textit{and} \quad w_t = w_{t+1} = \overline{w} \tag{3}$$

Functional forms

As far as soil pH is concerned, there are plenty of reports about the negative impacts of excessive pH values on crop growth, mostly caused by deficiency of metallic micronutrients (Cu, Zn, Mn, Fe). These adverse effects occur in neutral and basic soils with pH values above 7, which level is irrelevant in our study. Research results unanimously suggest that liming acidic soils increases gives a positive yield response and gradually, when approaching pH 7, a plateau is reached (see Lathwell and Reid, 1984). We operate exclusively in acidic soils, which have lower than optimal pH for the crops (see Havlin et al., 2005). Therefore, the Mitscherlich equation, not accounting for the decrease of the yield upon excessive inputs, is well reasoned in our study.

Lime (L): yield response and carry-over

Liming (u^l) is measured in tonnes per hectare (t/ha) and the stock of lime (x^l) is measured in soil *pH*. Liming has only an indirect effect on yield via soil *pH*. The yield response to the soil *pH* is described by a Mitscherlich function (Kempainen *et al.* 1993; Myyrä *et al.* 2003)

$$y(x_t^l, u_t^l) = 3748 - 29147862\, e^{-3.85\, pH_t} \tag{4}$$

The transition equation describing the carry-over effect and the effects of liming to the soil *pH* is (Kemppainen 1993)

$$x_{t+1}^l = pH_{t+1} = 0.049\, u_t^l + pH_t - 0.015 \tag{5}$$

With no liming, the average annual decay rate in the soil *pH* is 0.015 *pH*-points, which implies that annual amount of liming required for maintaining the existing *pH* level is on average, 0.3 tonnes per hectare. The initial state was set at $x_0^l = pH_0 = 5.8$, which was estimated to be an average on leased plots in central and northern parts of Finland (Myyrä *et al.* 2003). The prices and the scope of the model are summarised in Table 1.

Table 1: Prices and the scope of the optimisation problem.

Price of barley [a]	110 €/tonne
Price of lime [a]	
if applied 1-3 tonnes/ha	42.69 €/tonne
if applied 4-15 tonnes/ha	33.61 €/tonne
Discount factor (β)	1/1.05
Time horizon (T)	100 years
Duration of single contract (τ)	5 years

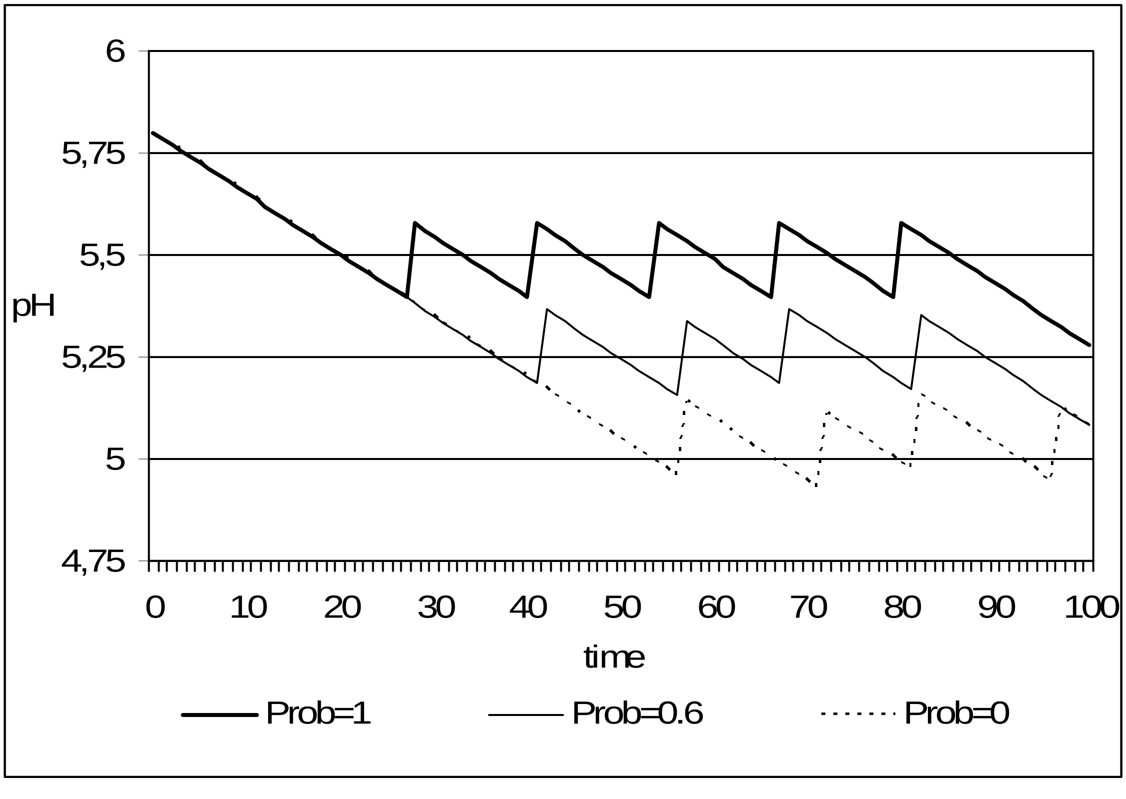
[a] The prices are at the farm gate. The price of liming includes field spreading. The spreading incurs an extra cost at low application rates.

Results

Liming is to some extent lumpy as it is expensive to distribute small amounts of lime (see the price thresholds in Table 1). Therefore, if the initial soil *pH* (5.8) is within the biological target range, which is the case in the simulations, land tenure insecurity does not make a difference in the optimal liming rules (Figure 1). It does not pay to apply lime on land with a *pH* level exceeding 5.4, except when farmer access to land certainly continues, either through repeated contract renewals or land ownership. In this case, the decision rule converges with the optimal behaviour around the long-run equilibrium without land tenure insecurity, which is also optimal for society.

When the initial *pH* level decreases[2] and soil acidity increases, decisions as to lime vary according to the uncertainty over the lease renewal (Figure 1). If the contract is going to expire with certainty, it pays to lime at the beginning of a five-year contract if, and only if, the soil *pH* is below an extremely low value of 5. If the odds are slightly in favour of contract renewal (*Prob*=0.6), it pays to lime at the beginning of the five-year contract if the soil *pH* is below 5.2.

Figure 1 : Development of soil *pH* in a sequence of 5-year lease contracts, conditional on alternative contract renewal probabilities (*Prob*). The upward sloping jumps in soil *pH* indicate points where lime is applied. The downward sloping line traces depletion of the soil *pH* when lime is not applied



The risk free long-run equilibrium is to maintain soil *pH* above 5.4, representing a “fair” soil *pH* status in the soil type studied. When contract renewal is likely, *e.g. Prob*>0.5, it

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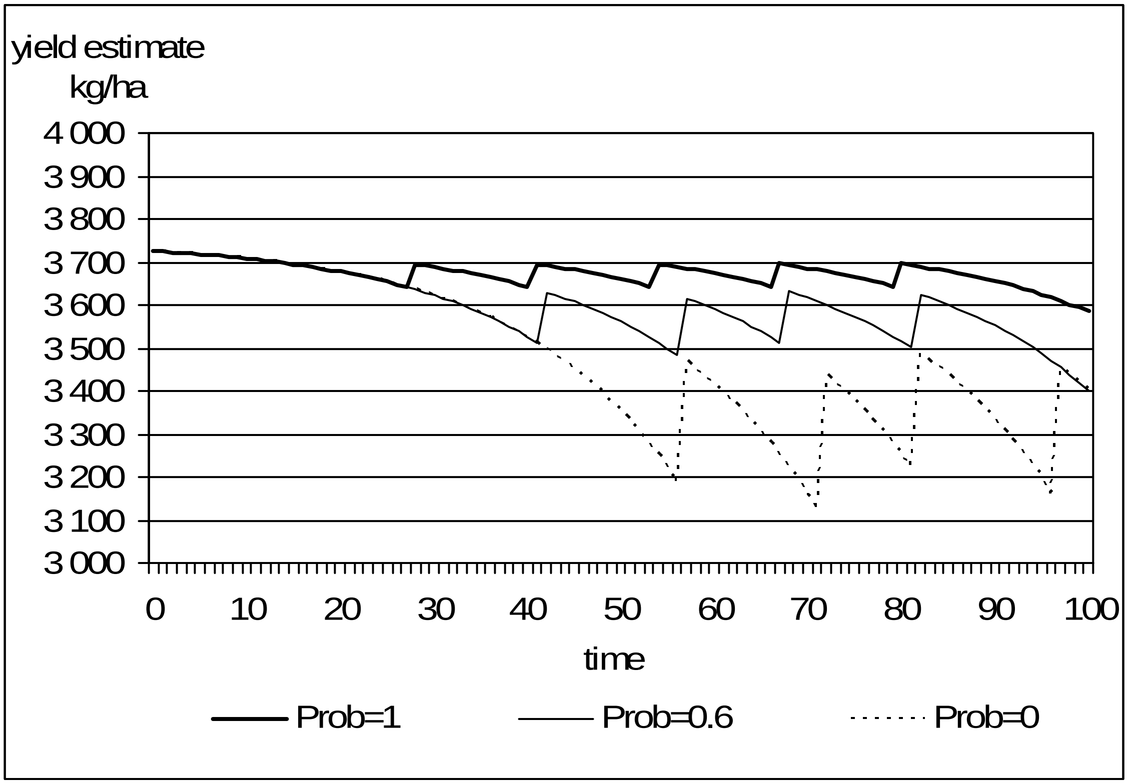
[2] The soils of Finland have been formed from acidic rock and *pH* values in agricultural soils are decreasing because the use of nitrogen fertilisers and acidic rain.

is still advantageous to maintain the soil *pH* above 5.2. Optimal timing is to apply liming immediately after the new contract is signed. Nevertheless, when the likelihood for contract renewal decreases and the odds are in favour of contract termination (*Prob*<0.5), the soil *pH* is allowed to decrease below 5.2, which most commonly represents the fertility class "rather poor" or "poor"[3].

If liming is neglected, it results in a gradually decreasing soil *pH* which will eventually decrease yields (*ceteris paribus*). Figure 2 traces out patterns of consequent five-year contracts summing to a 100-year period. When the land has been cultivated under several subsequent five-year lease contracts and the odds of continuity of the contract has been expected to be 0, an lease holders optimal policy leads to the yield of around 3,300 kg/ha. The yield decrease from the 3,670 kg/ha steady state equilibrium without land tenure insecurity is 230 kg/ha (in relative terms, 6 per cent). If the odds are slightly in favour of contract renewal (*Prob*=0.6) the steady state yield will be decreased only 120 kg/ha (3%) to 3,550 kg/ha.

Figure 2 : Predicted yield response to optimal liming under alternative probabilities (*Prob*) for a renewal of each five-year lease contract (*ceteris paribus*).



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[3] The class limits depend on the particle size distribution and the organic matter content of the soil.

Discussion

The results suggest that the optimal decision rules on irreversible land improvements with long pay-back periods vary substantially according to the extent of land tenure insecurity. Land improvements decrease below the social optimum when the likelihood for contract renewal decreases. Therefore, the current tendency of gradually increasing share of land cultivated under simple fixed duration cash lease contracts poses a problem in maintaining land improvements and soil fertility that are sufficient for maximising social welfare. This will finally turn into decreased yields and weakened food supply. Further, the incentive problems caused by land tenure insecurity will hamper the efficiency of environmental programmes to decrease nutrient run-offs since the standard is that also these programmes require irreversible land investments with long pay-back periods. Results also claims that required five-year contracts and commitments in agri-environmental programmes are too short to give real incentives to tenant for yield improving investments in leased plots. The results provide strong signals, and indeed justified concerns, to expect that land tenure insecurity will cause in the future more severe problems to land improvements than are currently being revealed by the statistics on soil *pH* (Myyrä *et al.* 2005).

The substantial implications, as suggested by our optimisation model, are supported by aggregate market behaviour even if this behaviour cannot, due to data limitations, be directly linked to land tenancy and uncertainty over contract renewals. The demand for lime has been decreasing rapidly as the share of land cultivated under lease contracts has been increasing. It has to be noted, however, that market trends have been affected also by other institutional and economic factors, such as the decreasing marginal value product for lime.

Our results hold only to simple cash lease contracts where the likelihood of contract renewal is exogenous. The results do not generalise repeated dynamic games in which the farmer’s reputation may have significant implications on optimal decision rules. Thus, our analysis does not account for the possibility that land improvements may be used to increase the likelihood of contract renewal (Sjaastad and Bromley 1997).

One of the main goals of the Common Agricultural Policy (CAP) in EU is to increase productivity in agriculture. The results signal that reaching this goal may be seriously hampered by gradually increasing land leasing unless the land tenure insecurity problem can be solved by better contract design. These contract designs must include the feedback from land fertility to land value, however one can claim that land prices are no longer driven by agricultural factors. One option to lower the uncertainty caused by fixed duration cash lease contracts would be to relax the legislative regulations on the maximum duration of land lease contracts.

The conclusion of this paper is that farmers (owners and tenants) may follow the socially optimal path in liming, if awareness of changes in land fertility is absolute, land productivity is valuated correctly and land lease markets are perfect. However, these conditions are not reached in simply cash lease contract markets.

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