economic incentives for soil conservation

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Abstract:

This paper presents a theoretical model to analyze the incentives for protecting soil productivity in presence of separation of property and control in agricultural land. Using a dynamic model of contracts between the landlords and operators we analyze the incentives of different type of contracts (fixed rate contracts or sharecropping contracts) and their potential impact on soil conservation. The main research question of this paper is: do landlords and tenants have conflicting incentives regarding soil conservation? Our theoretical results are consistent with previous empirical literature that find that, depending on the contract specifications, there are no conflicting incentives.

Acknowledegment:

JEL Codes: Q15, Q24

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ECONOMIC INCENTIVES FOR SOIL CONSERVATION: A DINAMIC GAME MODEL

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This paper presents a theoretical model to analyze the incentives for protecting soil productivity in presence of separation of property and control in agricultural land. Using a dynamic model of contracts between the landlords and operators we analyze the incentives of different type of contracts (fixed rate contracts or sharecropping contracts) and their potential impact on soil conservation. The main research question of this paper is: do landlords and tenants have conflicting incentives regarding soil conservation? Our theoretical results are consistent with previous empirical literature that find that, depending on the contract specifications, there are no conflicting incentives.

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Introduction

This paper presents a theoretical model to analyze the incentives for protecting soil productivity in presence of separation of property and control in agricultural land. Using a dynamic model of contracts between the landlords and operators we analyze the incentives of different type of contracts (fixed rate contracts or sharecropping contracts) and their potential impact on soil conservation. The main research question is: do landlords and tenants have conflicting incentives regarding soil conservation?

This issue is important for the discussion on public policy regarding agricultural contracts and soil conservation. The standard economic analysis, based on the property rights and transaction costs approach, suggest that landlords are the residual claimants and have incentives for taking care of the natural resources whether they exploit it themselves or they grant it to a third person for the productive activity.

The question that we analyze here is if landlords and tenants do have opposite incentives and how a contract can align incentives: On one hand incentives for preserving the resource productivity (landlord) and on the other incentives for overexploiting it (tenants) can be coordinated by a contract. First, we present a simple model that discuss which are the relevant variables in incentive alignment that will induce producers to protect the land productivity. Second, we analyze information problems that can impede the incentive compatibility.

This paper tries to formalize a practical problem to understand the incentives and factors that influence decisions. In the following section, we review the literature and we identify some relevant empirical findings. Then we present the theoretical model: a simple game theory model to understand the decision making process. We present a dynamic optimization model and determine theoretically which would be the soil nutrients stock in stationary status for the different type of contracts. Finally, we analyze the main results and predictions, and compare with other studies in theoretical and empirical literature. Final comments conclude.

Literature review

The subject on economic incentives for soil resource preservation has been approached from different perspectives; some authors have presented theoretical models for a better understanding of the problem, others have studied the empirical side, and some others have addressed both aspects.

Lee (1980) worked with data gathered from the combination of the 1977 National Resources Inventory (NRI) carried out by the US Soil Conservation Service (SCS) and the 1978 Land Ownership Survey conducted by the US Department of Agriculture (USDA). In his study, Lee provides an idea of the land tenure impact on soil conservation.

First of all, it is shown that corporations do not present average erosion rates higher than other landowners. At national level, and in most regions, there are no significant differences in erosion average rates as regards agricultural lands owned by different type of organizational units. Furthermore, with exception of the southeast region, there were no significant differences in the erosion average rates among different type of landowners, mainly due to management.

For non-corporative landowners, the results of this analysis are generally consistent with previous studies on farm net income, though there were no significant differences found between erosion rates and tenure groups. However, it was found that farm net income exercises more influence within the complete proprietor-operator tenure group than other tenure categories.

Finally, this analysis shows that there are regional differences, at least as regards income and tenure variables. Among five US regions which had presented erosion average rates in 5 ton/acre crops, income and tenure variables provided some sort of explanation for erosion differences in the northeast region, Corn Belt and Delta. However, there can be a more appropriate model for the Appalachia and Southeast region. Crop type characteristics in these regions, as well as landowners' attitudes as regards conservation, can provide some sort of explanation.

Burt (1981), through the approximately optimal decision rule approach which consists in a lineal approximation to the functional equation of dynamic programming in the "neighborhood" of the equilibrium state, shows that relatively high grain prices exacerbate soil erosion problems. However, empirical results for the Palouse suggest that wheat intensive production carried out with good cultural and fertilization practices is widely justified in the long term and for immediate net production as well. Additional topsoil and organic matter loss, compared to the use of a bigger amount of fodder in the cropping system, lies within economy boundaries and does not represent a threat for long term soil productivity.

In sloping areas, problems have their own characteristics and there should be a specialized crop system to be used without causing technical inefficiencies in modern farms on a large scale. Unless there is a substantial increase in fodder price in relation to cereal crops, it seems these conclusions will prevail in the foreseeable future. Though the analysis was done taking a relative price too low for alfalfa hay, technological change has significantly increased wheat production, and this should probably be more than enough. Direct sowing cultural practices combined with modern herbicides grants greater credibility to this conclusion.

McConnell (1983) introduces soil depth and loss in a simple agricultural production model, trying to determine when the private path to erosion differs from the socially optimal path. He develops an economic model for optimal private and social land use where he focuses on the intertemporal path in land use, including conditions under which private and social optimum differ.

He reaches the following results: first of all, an increase in soil loss does not mean that farmers ignore production physical relationships. A second implication is that if farmers realize baseline soil affects farm resale value, they will try to preserve it. A third conclusion refers to land use policy, where requiring that the soil eliminated each year should not be more than the natural resupplying therefore it presents radical consequences for farming policies and practices. This conclusion derives from maximizing generation's minimum welfare.

Lee and Stewart (1983) used a logit model with data gathered through the combination of the National Resource Inventory (NRI) from 1977 and the Land Ownership Survey conducted by the US National Department of Agriculture; they were concentrated exclusively on farming lands[1] and worked with 7649 observations of the fused sample which fulfilled the criteria, establishing a random sample of every non-federal farming unit population in the 48 states during 1977 and 1978.

In their study they conclude that small size operations represent more of an obstacle for adopting minimum tillage than property detachment from farm operation. Differences would not confirm the usual hypothesis about the effect of property detachment and farm operation on soil conservation. In contrast, using minimum tillage is not so common among landowners who only operate on lands that they possess. Furthermore, though land leasing data was not included in this analysis, the authors consider that tenure impact was significant in every region, including those regions such as Corn Belt where percentage leasing is very common (moreover, there was not a significant interaction impact between tenure and the region). This suggests that leasing agreements do not alter the basic relationship between tenure and the use of minimum tillage.

After considering land tenure classification and farm size, analysis indicates that in some regions minimum tillage is slightly more probable to be used in non-erosive lands than in erosive lands. Therefore, this suggests that soil conservation can become a secondary motivation in the use of minimum tillage.

In his study, Pagiola (1999) establishes that decisions on land use are taken by farmers, not by social planners or government agencies. Farmers are the ones who decide how to

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[1] Farming lands defined as inline tilling lands, closed field farming, summer fallowing, or hay and pasture rotation.

use their lands according to their own goals, possibilities and limitations. But they also take into account what society would like farmers to do. Even when society presents clearly articulated social goals, such as “sustainable development”, it becomes difficult to turn these goals into land individual user’s actions, particularly due to specific farming production site characteristics, soil degradation problems and the lack of data.

Therefore, Pagiola concludes that farmers tend to have strong incentives for using conservation measures when soil degradation threatens their land`s long term productivity. When degradation becomes worrisome, mainly due to its impact on productivity, differences between optimal conservation behavior and socially optimal behavior are generally brought on by variation in products and supplies costs or by restrictions that prevent farmers from adopting conservation practices that would otherwise be profitable. Unless these problems are addressed directly, it is unlikely that any incentive model would turn out effective. On the contrary, when degradation becomes a problem due to its impact outside the land, farmers lack direct incentive for taking appropriate corrective measures.

Allen and Lueck (2003) proposed that rental contracts for a percentage of the harvested crop discourage the use of the input since they affect the marginal product of the inputs. This is because part of the marginal product of the input is captured by the owner of the land through the amount received in rent, reducing the marginal product that the producer receives; that leads him to use a smaller amount of inputs.

Gallacher (2004) finds out there are no a priori reasons to infer that a reduction in the percentage of owner controlled lands will necessarily lead to a lower conservation level. On the contrary, it is possible that land leasing could make resources allocation become more flexible and it could also facilitate an injection of capital for the agricultural sector, reducing producers funding costs and therefore lowering future income discount rates. On the other hand, he claims that land leasing allows businessmen with limited land areas to generate additional income by selling agricultural work and in this way help them reduce pressure to increase land use.

Brescia and Lema (2004) worked with data from the Agricultural National Census (ANC-2002) for Pergamino County in Argentina and also with a survey to farmers carried out by INTA’s Project “FERTILIZAR”. Brescia and Lema (2006) also used microdata from the Agricultural National Census (ANC - 2002) for Entre Rios Province. In both papers, results showed a lack of differential impact between landowners and tenant farmers as regards both adopting soil conservation practices and using productive agricultural inputs and methods as well. This would aim at promoting the hypothesis that both landowners who farm their land and tenant farmers have the same incentive for using similar soil conservation productive techniques.

In a recent paper, Arora et al (2015), empirically address the effects of different land tenure systems. They conduct interviews and a survey to farmers and decision-makers in in the “Pampean” region of Argentina There were two main questions: whether land tenure has an influence on agribusiness decision-makers’ economic and social goals, and also if differences in goals based on land tenure reflect differences in agricultural or economic practices and attitudes towards the environment. The aim was to explore the distinction between farmer’s goals working on leased lands and in owned lands. In particular, the focus was on goals and decisions that impact on soil conservation.

The survey results suggest that landowners present a long-term approach to their economic and social goals paying greater attention to their personal goals, while tenants focus on short term goals in order to ensure profit maximization and fulfill social obligations. These differences between landowners and tenants’ goals seem to influence land use, financial instruments use and environmental attitudes. Tenants are more likely to grow soybean which needs a lower initial investment. It is also more probable that they use futures and options markets, use different options to manage price risk and worry less about environment problems.

Since a great part of land is rented by those decision-makers who also owned lands, interviews were conducted in order to try to differentiate these people’s goals and motivation, taking into account if the land was owned or rented. The results show tenure impact on underlying intentions where the same person pays attention to how a particular action improves the long term value of the owned land. But it is also shown that they were more worried about increasing profits from a leased land. As a result, tenants prefer to grow soybean, which is a low investment crop and they frequently ignore conservation practices, such as crop rotation. Furthermore, this study suggests that though 85% of the leased land is renewed each year, operators ignore a possible long-term association with rented lands, and they concentrate on maximizing short term profits. According to the authors, this creates a dilemma for tenants, who by taking a short-term perspective, ignore that in some point in the future they will have to face long term consequences of their actions which are not clearly perceived by the tenant or landowner. To explain this point, they refer to a sequential game between two people where a sort of “prisoner’s dilemma” exists because the current tenant and the future tenant, who are often the same person, maximize the lease terms, acting as if there were no chances for them to farm the land in the future. Thus, they create a situation where the additive impact of their rational actions over the course of time becomes “irrational” given that the game leads them to take the most profitable short-term solution that nevertheless, is not optimal in the long term.

Finally, they conclude that not only tenants are not being rational in their approach as regards the land, but also that the land owners that do not take into account the consequences of soil degradation.

Lema and Benito (2016) claim that landowners’ private decisions on agricultural soil are efficient and lead to optimal behaviors as regards asset value preservation, since it is supposed these decisions are made through the land market, where property rights are properly defined. They choose a dynamic optimization formal model which shows that if prices appropriately reflect resources opportunity costs, the key variables to ensure an efficient soil use include intertemporal discount rates, benefits and costs associated to land production and preservation as well as working-time horizon. A significant point shown in the study is that the decentralized solution proves to be optimum both for agents with an infinite horizon as well as for agents with a limited horizon, under an appropriate functioning of the market and assuming that there are no distortions derived from regulations or taxes.

A Dynamic Game Model

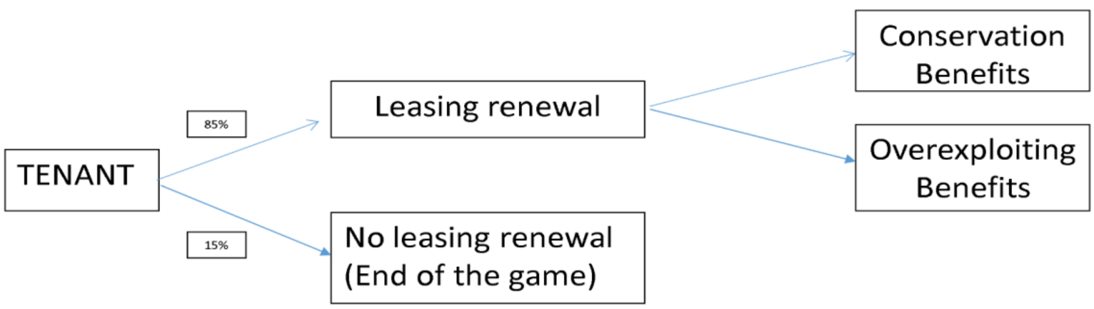
Arora et al (2015) present a two participants sequential game, where each player plays only one turn and where during the initial term the tenant “ignores” he will be the tenant in the second term. We use this basic scheme for the game. Our contribution is to modify the information setting, because in our opinion is not suitable to explain the real behavior in the land market. If the tenant is rational, even without complete information, he should know or at least be able to estimate the probability of lease renewal (the % of probabilities of continuing exploiting the land) and he would play differently.

The model we suggest is a sequential game repeated infinitely considering that there are doubts as regards when the game will end (during each term, we specifically added a 15% probability to end the game). During several game stages, players (both the landowner and the tenant being the same in each stage) complete a specific game (always the same one) called stage game. Results are shown at the end of each stage, and the players receive the corresponding payment.

In order to simplify the analysis to set the game, we will assume that the profits are the same in each point of time. This is a game with incomplete information since the landowner payment capacity is unknown, and therefore there is uncertainty about when he is going to stop renting the land; but what is actually known is that there is 85% probability for the lease to be renewed being this one of the possible actions to be taken according to his strategic profile. Meanwhile, there is a 15% probability for the lease not to be renewed which would be the move that ends the game[2].

For his part, the tenant can take two actions: i) to exhaust the natural resource that grants him benefit π_s or ii) to use the land according to the best agricultural practices expected by the landowner π_c. We assume that once the tenant starts to deplete the soil, he will not be able to stop until the soil is completely exhausted. This means that once he decides to overexploit, he will not be able to change and use a soil conservation practice.

The extensive form of the game is:



[2] We assume a probability of renewal of 85% following the Arora et al. (2015) paper.

When this game is infinitely repeated there are two possible optimal strategies (because we assumed there were only two payments constant over time): i) to always overexploit until the resource is depleted or ii) to perform good practices or "conservationist" practices. Beginning to deplete after behaving in a conservationist is as a strategy dominated bye by any of the other two strategies.

The present value of land depletion is:

$$\pi_s * \frac{\lambda*(1+r)^n - \lambda^{n+1}}{(1+r-\lambda)*(1+r)^n} \text{ (i)}$$

Where:

λ: land leasing renewal probability

r: real interest rate

n: number of periods land stays productive before becoming depleted, allowing a constant profit π_s per period

The present value of adopting conservationist practices is:

$$\pi_c * \frac{\lambda}{(1+r-\lambda)} \text{ (ii)}$$

Therefore, if depletion is the dominant strategy, the following condition should be met:

$$\frac{\pi_s}{\pi_c} \geq \frac{(1+r)^n}{(1+r)^n - \lambda^n} \text{ (iii) (Appendix I)}$$

Table 1 presents the indifference ratios between depletion benefits and conservation benefits. This implies that for overexploiting the land in this game it is necessary that the depletion profits outweigh the conservation profits the number of times reported in the cells.

Table 1. Indifference Ratio between depletion profits and conservation profits – Probability of renewal 85%

n\r	0.01	0.05	0.1	0.25	0.5	1
1	6.3125	5.2500	4.4000	3.1250	2.3077	1.7391
5	1.7306	1.5329	1.3803	1.1701	1.0621	1.0141
10	1.2169	1.1375	1.0821	1.0216	1.0034	1.0002
25	1.0136	1.0051	1.0016	1.0001	1.0000	1.0000

We can see that the higher the interest rate and the longer the time period, the resource can be overexploited, the smaller is the difference between overexploitation and conservation benefits needed to deplete the soil.

If the probability for contract renewal is 10% the results are modified as shown in Table 2.

Table 2. Indifference Ratio between depletion profits and conservation profits – Probability of renewal 10%

n\r	0.01	0.05	0.1	0.25	0.5	1
1	1.1099	1.1053	1.1000	1.0870	1.0714	1.0526
5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
10	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
25	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

If the probability of renewal is 50% the results are:

Table 3. Indifference Ratio between depletion profits and conservation profits – Probability of renewal 50%

n\r	0.01	0.05	0.1	0.25	0.5	1
1	1.9804	1.9091	1.8333	1.6667	1.5000	1.3333
5	1.0306	1.0251	1.0198	1.0103	1.0041	1.0010
10	1.0009	1.0006	1.0004	1.0001	1.0000	1.0000
25	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

If the renewal probability is 100%[3]:

Table 4. Indifference Ratio between depletion profits and conservation profits – Probability of renewal 100%

[3]That the probability of renewing next year is 100% is different from being a contract for a longer term and is analyzing the comparison from one year to another.

n\r	0.01	0.05	0.1	0.25	0.5	1
1	101.0000	21.0000	11.0000	5.0000	3.0000	2.0000
5	20.6040	4.6195	2.6380	1.4874	1.1517	1.0323
10	10.5582	2.5901	1.6275	1.1203	1.0176	1.0010
25	4.5407	1.4190	1.1017	1.0038	1.0000	1.0000

As expected, as probability of contract renewal increases, there is also an increase in the indifference profit ratio required for depleting the soil. If the contracts are set for a longer period of time, we find out that the game remains the same, a sequential game repeated endlessly.

The profits of both, depletion and conservation arise from the sum of annual benefits minus cost increase[4], multiplied the length of the contract[5] and the total benefits would be the aggregation of one these two actions: overexploiting or conservation. A change of strategy would be irrational. Since this problem is solved by backward induction, what is decided in the last period will determine the actions in previous periods.

Therefore, the game payoffs could be defined as following:

1. Benefits of land depletion throughout the whole lease:

$${\pi_s}^{Clp} = (\pi_s - \mathrm{C}) * \frac{(1+r)^i - 1}{r*(1+r)^i} \text{ (iv)}$$

2. Benefits of conservation throughout the whole lease:

$${\pi_c}^{Clp} = (\pi_c - \mathrm{C}) * \frac{(1+r)^i - 1}{r*(1+r)^i} \text{ (v)}$$

Where this represents leasing length and C represents annual rent cost increase (if C is greater than 0) or reduction (if C is less than 0) due to long term lease.

We can redefine the game to consider long term contracts. The present value of profits from soil depletion are:

[4] It takes into account rent price raising o reduction, transaction costs, etc. This variable may take negative or positive value as applicable.
[5] We suppose that contract length is going to be a dividing number of the number of years that the resource lasts, so as to simplify the process in the model

$$\pi_s{}^{Clp} * \frac{\delta*(1+k)^j-\delta^{j+1}}{(1+k-\delta)*(1+k)^j} \text{ (vi)}$$

Where δ represents the probability for leasing renewal, $j = n/i$: represents the number of years during land stays productive, before depletion, and profits are $\pi_s{}^{Clp}$ for each contract.

$k = (1+r)^i - 1$ represents discount rates used for evaluating the contracts.

The present value of profits from conservation practices are:

$$\pi_c * \frac{\lambda}{(1+r-\lambda)} \text{ (ii)}$$

For soil depletion becoming the dominant strategy this condition should be met:

$$\frac{\pi_s{}^{Clp}}{\pi_c{}^{Clp}} \geq \frac{(1+k)^j}{(1+k)^j-\delta^j} \text{ (viii)}$$

This way we can calculate what should be the difference as regards renewal probabilities for a long term leasing contract to become more convenient than a short term one:

$$\delta \geq \left(\frac{\lambda^n}{-C+\frac{C*\lambda^n}{(1+r)^n}+1}\right)^{\frac{1}{j}} \text{(ix) (See Appendix 2)}$$

Through this equation we can conclude that the longer the contract length, the fewer renewal probabilities needed for the contract to become more convenient than one year contracts with resource conservation goals.

Below, Tables 5, 6,7 and 8 presents different variations of costs (C) associated to long term leasing contracts. We presents the results for the minimum renewal probability needed for a 5-year contract to be more convenient or the same than a 1-year contract with 85% renewal probability in order to induce soil conservation practices.

Table 5. Cost Variation: -20%.

n\r	0.01	0.05	0.1	0.15	0.2	0.5	1
7	0.404012	0.400447	0.397339	0.395213	0.393729	0.390399	0.389642
8	0.406664	0.403721	0.401254	0.399638	0.398555	0.396358	0.395963
10	0.411199	0.409188	0.407632	0.406698	0.406123	0.405161	0.405052
15	0.419303	0.418522	0.418029	0.417792	0.417674	0.417547	0.417543
18	0.422673	0.422230	0.421982	0.421878	0.421833	0.421794	0.421793
21	0.425308	0.425056	0.424931	0.424886	0.424868	0.424856	0.424856
25	0.428009	0.427890	0.427840	0.427825	0.427820	0.427817	0.427817
28	0.429594	0.429526	0.429501	0.429495	0.429493	0.429492	0.429492
50	0.435690	0.435689	0.435689	0.435689	0.435689	0.435689	0.435689

Table 6. Cost Variation: 0%.

n\r	0.01	0.05	0.1	0.15	0.2	0.5	1
7	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053
8	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053
10	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053
15	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053
18	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053
21	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053
25	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053
28	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053
50	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053	0.4437053

Table 7. Cost Variation: +25%.

n\r	0.01	0.05	0.1	0.15	0.2	0.5	1
7	0.5091710	0.5171661	0.5245369	0.5298080	0.5336059	0.5425035	0.5446001
8	0.5050310	0.5116666	0.5175078	0.5214817	0.5242123	0.5299331	0.5309884
10	0.4977739	0.5023278	0.5059857	0.5082411	0.5096530	0.5120555	0.5123303
15	0.4843450	0.4861019	0.4872314	0.4877797	0.4880536	0.4883501	0.4883607
18	0.4786408	0.4796305	0.4801893	0.4804250	0.4805281	0.4806162	0.4806178
21	0.4741597	0.4747174	0.4749945	0.4750963	0.4751353	0.4751620	0.4751623
25	0.4695642	0.4698243	0.4699335	0.4699669	0.4699776	0.4699832	0.4699832
28	0.4668730	0.4670200	0.4670745	0.4670890	0.4670931	0.4670949	0.4670949
50	0.4566526	0.4566549	0.4566553	0.4566553	0.4566553	0.4566553	0.4566553

Table 8. Cost Variation: +50%.

n\r	0.01	0.05	0.1	0.15	0.2	0.5	1
7	0.6038996	0.6287042	0.6529377	0.6711463	0.6847539	0.7183724	0.7266748
8	0.5947215	0.6155941	0.6349760	0.6487488	0.6585063	0.6797789	0.6838323
10	0.5780894	0.5926976	0.6049548	0.6127614	0.6177498	0.6264256	0.6274338
15	0.5456772	0.5514161	0.5551903	0.5570474	0.5579811	0.5589965	0.5590332
18	0.5313998	0.5346314	0.5364826	0.5372696	0.5376148	0.5379101	0.5379155
21	0.5200444	0.5218586	0.5227681	0.5231035	0.5232321	0.5233205	0.5233213
25	0.5083275	0.5091674	0.5095219	0.5096303	0.5096652	0.5096835	0.5096836
28	0.5014557	0.5019279	0.5021035	0.5021502	0.5021634	0.5021691	0.5021691
50	0.4755430	0.4755504	0.4755515	0.4755516	0.4755516	0.4755516	0.4755516

These figures show that as long as there is an increase in costs associated to long-term contracts (in this case, 5 years), there must be a higher renewal probability to sustain the equilibrium with an indifference 85% probability of short term renewal contract.

Dynamic Model and Optimal Trajectory:

We introduce in the model the use of fertilizers. We assume:

Assumptions:

- 1 output
- 2 inputs $\{ f_t, q_t\}$
- nutrients in the soil (stock) ${f^T}_t$
- Production function: $\phi_0 + \phi_f * \ln({f^T}_t + f_t) + \phi_q * \ln(q_t)$
- Cost function: $c_q * q_t + c_f * f_t + A_t$

A_t land rent

- The transition function of the nutrient stock in the soil:

$$\dot{f^T}_t = f_t - \gamma * [\phi_0 + \phi_f * \ln({f^T}_t + f_t) + \phi_q * \ln(q_t)]$$

γ Represents the net balance of nutrients obtained from the product (crop)

The problem of the producer is:

$$\max_{ft,qt} \int_0^\infty e^{-\rho_i * t}(\phi_0 + \phi_f * \ln({f^T}_t + f_t) + \phi_q * \ln(q_t) - c_q * q_t - c_f * f_t - A_t)$$

Subject to: $\dot{f^T}_t = f_t - \gamma * [\phi_0 + \phi_f * \ln({f^T}_t + f_t) + \phi_q * \ln(q_t)]$

$$\rho_i = \ln(1 + r) - \ln \psi$$

$$0 < \rho_i < 1$$

Where ψ is the probability of renewal of the lease and r is the annual real interest rate. ρ_i is the discount rate for the type of tenure i.

We present 3 alternatives:

1. a tenant who pays a fixed rent
2. a tenant who pays a percentage of the crop harvested (sharecropping)
3. the landlord operates the farm

1. Fixed rent

$$H = \phi_0 + \phi_f * \ln\left({f^T}_t + f_t\right) + \phi_q * \ln(q_t) - c_q * q_t - c_f * f_t - A_t + \lambda_t * [f_t - \gamma * [\phi_0 + \phi_f * \ln\left({f^T}_t + f_t\right) + \phi_q * \ln(q_t)]]$$

λ_t is the shadow price of the unit of the nutrient stock on the soil

The first order conditions (FOC´s) are:

$$\frac{dH}{dq_t} = {}^{\phi_q}\!/_{q_t} - c_q - \lambda_t * \gamma * {}^{\phi_q}\!/_{q_t} = 0 \qquad (1)$$

$$\frac{dH}{df_t} = {}^{\phi_f}\!\Big/_{({f^T}_t + f_t)} - c_f + \lambda_t * \left[1 - \gamma * {}^{\phi_f}\!\Big/_{({f^T}_t + f_t)}\right] = 0 \qquad (2)$$

$$\frac{dH}{d\lambda} = f_t - \gamma * \left[\phi_0 + \phi_f * \ln\left({f^T}_t + f_t\right) + \phi_q * \ln(q_t)\right] = {f^{\dot{T}}}_t \qquad (3)$$

$$\frac{dH}{d{f^T}_{t_t}} = {}^{\phi_f}\!\Big/_{({f^T}_t + f_t)} - \lambda_t * \gamma * {}^{\phi_f}\!\Big/_{({f^T}_t + f_t)} = \lambda_t * \rho_i - \dot{\lambda}_t \qquad (4)$$

For fixed rent contract, the variable A_t is not present in the FOC´s, so the solution for the tenant and the landlord operator are practically the same. The difference is in the value that takes ρ_i given that in the case of the owner-producer ψ = 1 and in the case of the tenant ψ <1.

From (1) and (2) we obtain the optimal input levels

$$(1 - \lambda_t * \gamma) * {}^{\phi_q}\!/_{c_q} = q_t \qquad (1')$$

$$(1-\lambda_t*\gamma)*{}^{\phi_f}\!/_{(c_f-\lambda_t)}-f^T{}_t=f_t \qquad (2')$$

Using (3) and (4) and replacing in (1 ') and (2'):

$$\dot{\lambda}_t=\lambda_t*(1+\rho_I)-c_f \qquad (5)$$

$$\dot{f^T}_t=\frac{\phi_f*(1-\lambda_t*\gamma)}{(c_f-\lambda_t)}-f^T{}_t-\gamma*\left[\phi_0+\phi_f*\ln\left(\frac{\phi_f*(1-\lambda_t*\gamma)}{(c_f-\lambda_t)}\right)+\phi_q*\ln\left(\frac{\phi_q*(1-\lambda_t*\gamma)}{c_q}\right)\right](6)$$

The steady state is:

$$\lambda_t^{EE}={}^{c_f}\!/_{(1+\rho_I)} \qquad (7)$$

$$f^T{}_t{}^{EE}=\frac{\phi_f*\left(1-{}^{c_f}\!/_{(1+\rho_I)}*\gamma\right)}{\left(c_f-{}^{c_f}\!/_{(1+\rho_I)}\right)}-\gamma*\left[\phi_0+\phi_f*\ln\left(\frac{\phi_f*\left(1-{}^{c_f}\!/_{(1+\rho_I)}*\gamma\right)}{\left(c_f-{}^{c_f}\!/_{(1+\rho_I)}\right)}\right)+\phi_q*\right.$$
$$\left.\ln\left(\frac{\phi_q*\left(1-{}^{c_f}\!/_{(1+\rho_I)}*\gamma\right)}{c_q}\right)\right] \qquad (8)$$

2. Sharecropping.

If the rent is payed as a percentage of the production (α):

$$H=(1-\alpha)*\phi_0+(1-\alpha)*\phi_f*\ln\left(f^T{}_t+f_t\right)+(1-\alpha)*\phi_q*\ln(q_t)-c_q*q_t$$
$$-c_f*f_t-A_t+\lambda_t*[f_t-\gamma*[\phi_0+\phi_f*\ln\left(f^T{}_t+f_t\right)+\phi_q*\ln(q_t)]]$$

The FOC´s are:

$$\frac{dH}{dq_t}=(1-\alpha)*{}^{\phi_q}\!/_{q_t}-c_q-\lambda_t*\gamma*{}^{\phi_q}\!/_{q_t}=0 \qquad (9)$$

$$\frac{dH}{df_t}=(1-\alpha)*{}^{\phi_f}\!/_{\left(f^T{}_t+f_t\right)}-c_f+\lambda_t*\left[1-\gamma*{}^{\phi_f}\!/_{\left(f^T{}_t+f_t\right)}\right]=0 \qquad (10)$$

$$\frac{dH}{d\lambda}=f_t-\gamma*\left[\phi_0+\phi_f*\ln\left(f^T{}_t+f_t\right)+\phi_q*\ln(q_t)\right]=\dot{f^T}_t \qquad (11)$$

$$\frac{dH}{df^{T}{}_{t_t}} = (1-\alpha) * {}^{\phi_f}\Big/_{(f^T{}_t + f_t)} - \lambda_t * \gamma * {}^{\phi_f}\Big/_{(f^T{}_t + f_t)} = \lambda_t * \rho_i - \dot{\lambda}_t \qquad (12)$$

From (9) and (10) the optimal input levels are:

$$(1-\alpha-\lambda_t * \gamma) * {}^{\phi_q}/_{c_q} = q_t \qquad (9')$$

$$(1-\alpha-\lambda_t * \gamma) * {}^{\phi_f}\Big/_{(c_f - \lambda_t)} - f^T{}_t = f_t \qquad (10')$$

Using (11) and (12) and replacing in (9 ') and (10':

$$\dot{\lambda}_t = \lambda_t * (1+\rho_I) - c_f \qquad (13)$$

$$\dot{f^T}{}_t = \frac{\phi_f * (1-\alpha-\lambda_t * \gamma)}{(c_f - \lambda_t)} - f^T{}_t - \gamma * \left[\phi_0 + \phi_f * \ln\left(\frac{\phi_f * (1-\alpha-\lambda_t * \gamma)}{(c_f-\lambda_t)}\right) + \phi_q * \ln\left(\frac{\phi_q * (1-\alpha-\lambda_t * \gamma)}{c_q}\right)\right] (14)$$

The steady state is:

$$\lambda_t{}^{EE} = {}^{c_f}\Big/_{(1+\rho_I)} \qquad (15)$$

$$f^T{}_t{}^{EE} = \frac{\phi_f * \left(1-\alpha-{}^{c_f}/_{(1+\rho_I)} * \gamma\right)}{\left(c_f - {}^{c_f}/_{(1+\rho_I)}\right)} - \gamma * \left[\phi_0 + \phi_f * \ln\left(\frac{\phi_f * \left(1-\alpha-{}^{c_f}/_{(1+\rho_I)} * \gamma\right)}{\left(c_f - {}^{c_f}/_{(1+\rho_I)}\right)}\right) + \phi_q * \ln\left(\frac{\phi_q * \left(1-\alpha-{}^{c_f}/_{(1+\rho_I)} * \gamma\right)}{c_q}\right)\right] \qquad (16)$$

The steady state obtained in (16) is different from that obtained in (8) for equal renewal probability rates[6], and the difference is entirely attributable to using a sharecropping contract, since this reduces the marginal income obtained by increasing the inputs.

The steady state with a sharecropping contract will then be lower when the following condition is met:

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[6]The probability of exogenous renewal is assumed for simplicity to make the comparison simpler; in the case of percentage contracts, this could be thought to be endogenous to crop yield

$$0 > \frac{\phi_q}{\phi_f} + \frac{\alpha - 1}{\left(\frac{c_f * \rho_I * \gamma}{\rho_I + 1}\right)} + \frac{(\rho_I + 1)}{\rho_I}$$

Next, characterize the system of differential equations of first order in the neighborhood of the steady state. Since the models are similar, we take the case of the sharecropping contract. To obtain the results for fixed rent contracts is straightforward turning the α equal to zero.

First we linearize the system around the Steady State:

$$\begin{pmatrix} \dot{\lambda}_t \\ \dot{f^T}_t \end{pmatrix} = \begin{pmatrix} (1+\rho_I) & 0 \\ \frac{-\phi_f * (1 - \alpha - \gamma * {c_f}/{(1+\rho_I)})}{(c_f * {\rho_I}/{(1+\rho_I)})^2} + \gamma^2 * \frac{(\phi_f - \phi_q)}{(1 - \alpha - {c_f}/{(1+\rho_I)} * \gamma)} & -1 \end{pmatrix} * \begin{pmatrix} \lambda_t \\ {f^T}_t \end{pmatrix}$$

The Trace is: $\rho_I > 0$

The determinant is: $-1 - \rho_I < 0$

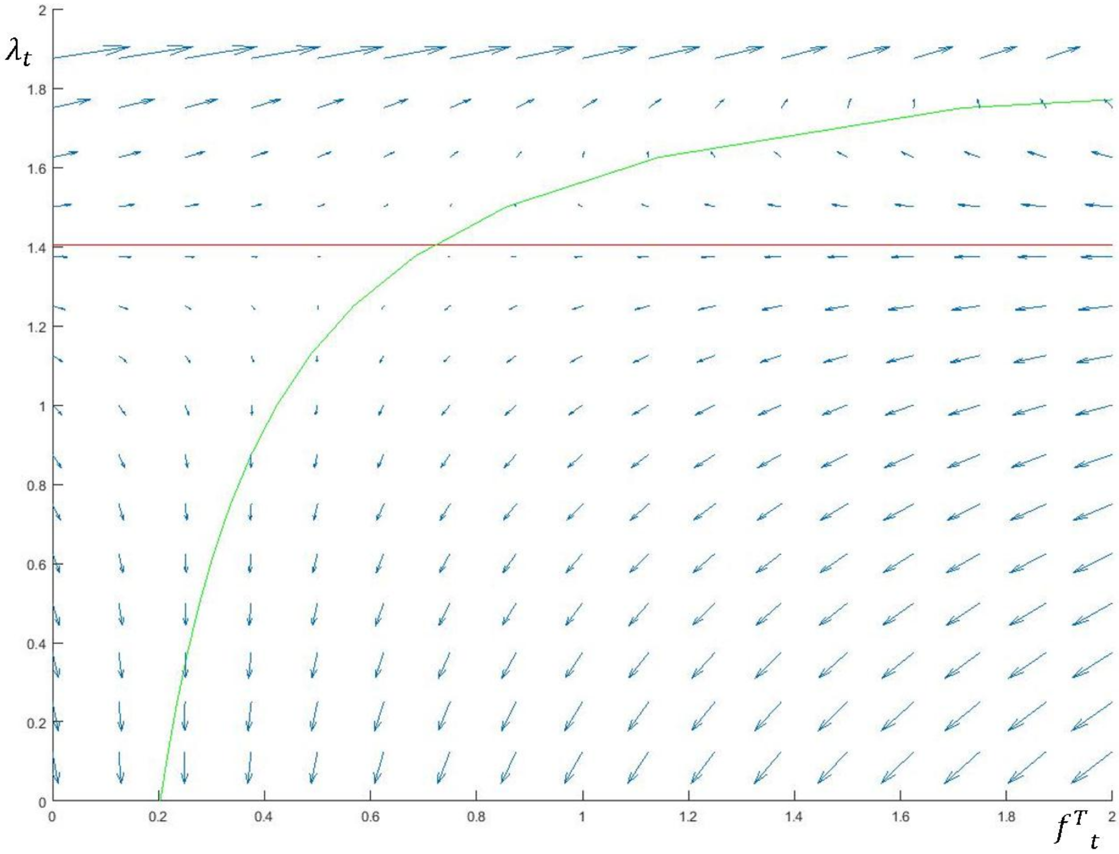
The discriminant is: ${\rho_I}^2 + 4 * (1 + \rho_I) > 0$

Since the determinant is negative, the system is a saddle point. The relevant point is in $\dot{f^T}_t = 0$ that when $\lambda_t \rightarrow c_f$ it is observed that ${f^T}_t \rightarrow \infty$.

Regarding the variation of the steady state with respect to the discount rate (relevant variable, that can be consider endogenous to the probability of contract renewal), we can say that the higher the discount rate, the lower the shadow price in the Steady State, and lower will be the steady state nutrient stock.

Figure 1 presents the phase diagram that describes the time path of the nutrient stock (horizontal axis) and the shadow price of nutrient stock (vertical axis)

Figure 1. Phase Diagram



Discussion

The results of the model show that for 1% or 5% actual interest rates, and if the soil allows a 5 year overexploitation, with 85% renewal option, it is required that depletion profits become 73% and 53% higher than conservation benefits to be convenient. On the other hand, if the resource can be exploited over a 10-year period, it is necessary for each year to show 21% and 13% higher benefits, as regards conservation benefits to decide depleting the soil.

Moreover, the model allows us to analyze the renewal probability for a long-term leasing contract to be superior to a short-term contract as regards land conservation. Comparing a 5-year-contract, where the resource may be exploited for 10 years, and a 1-year-contract with 85% renewal option, with 1% and 5% real interest rates, we can notice that long-term contracts' product costs variation appears as the relevant variable to be taken into account when defining renewal probability.

If cost falls 20%, the long-term contract renewal probability must be 41% for both interest rates. While if costs rise 50%, the required renewal probability would be 57% for a 1% discount rate and 59% for a 5% discount rate.

This suggests that a long-term contract is not always better than a short-term one, since it depends on costs associated to the contract duration, and long-term renewal probability. A basic result of this model is that if the contract have zero renewal probability, the tenant would overexploit the land. Profit maximization leads to land overexploitation in order to reach the end of the contract leaving an unproductive land.

As regards empirical implications, the theoretical results presented in this study questions whether land resource can be overexploited systematically due to the land tenure system. In a recent study Alvares et al. (2015) found out widespread soil damage due to the agricultural practices performed during the twentieth century in the Pampean prairie in Argentina. But, soil quality changes for the most part do not reach critical values. They compare soil carbon content between 1960 and 1980 and the present day, and they do not find significant regional changes.

Therefore, this suggests that during the last decades, soil total organic matter in the Pampas has not significantly changed. On the other hand, they found evidence that nitrogen and phosphorus balances, which result from the difference between nutrients balance, are now as negative as they have always been historically in this region. However, this is not explicitly related to the type of land tenure system or to lease contract duration. If it is analyzed using the dynamic optimization model proposed above, the nitrogen and phosphorus balances that are currently negative can be thought of as not having reached the steady state values.

Final Comments

This paper developed a theoretical model to study the relationship with land tenure and soil conservation. Results suggest that practices related to soil conservation for different contracts between landowners and tenants will depend on:

i. Interest rate: the higher the interest rate, the bigger the incentive to deplete the resource.

ii. Number of periods during which the resource can be overexploited until it is depleted: the larger the number of periods for overexploiting the resource, the more incentives there will be for not preserving the resource.
iii. Contract renewal probability: the smaller the renewal probability, the more incentives there will be for overexploiting the resource.
iv. Differences between overexploitation and conservationist practices profits.

As regards incentives for protecting land nutrients stock, the dynamic model shows that there may be differences among tenure types. Steady state conditions for the different kind of contracts may differ according to two variables:

- Discount rates: it depends on the interest rate perceived by the agent (landowners and tenants) and contract renewal probability as regards the tenants.
- Harvest percentage received by landowners in the case of sharecropping (which is zero if it is a fixed lease or if the land is exploited by the landowner).

Finally regarding the main research question of this paper: do landlords and tenants have conflicting incentives regarding soil conservation? Our theoretical results are consistent with previous empirical literature that find that, depending on the contract specifications, there are no conflicting incentives.

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Appendix I (equation ii)

$$\pi_s * \frac{\lambda * (1+r)^n - \lambda^{n+1}}{(1+r-\lambda) * (1+r)^n} \geq \pi_c * \frac{\lambda}{(1+r-\lambda)}$$

$$\frac{\pi_s}{\pi_c} \geq \frac{\lambda}{(1+r-\lambda)} * \frac{(1+r-\lambda) * (1+r)^n}{\lambda * (1+r)^n - \lambda^{n+1}}$$

$$\frac{\pi_s}{\pi_c} \geq \frac{\lambda * (1+r)^n}{\lambda * (1+r)^n - \lambda^{n+1}}$$

$$\frac{\pi_s}{\pi_c} \geq \frac{\lambda * (1+r)^n}{\lambda * ((1+r)^n - \lambda^n)}$$

$$\frac{\pi_s}{\pi_c} \geq \frac{(1+r)^n}{(1+r)^n - \lambda^n}$$

Appendix II (equation 7)

assuming $\pi_c = 1$

The condition of indifference for contracts with terms of more than one year:

$$\frac{\pi_s - C}{1 - C} \geq \frac{(1+k)^j}{(1+k)^j - \delta^j}$$

I know that: $j = n/i$ and $k = (1+r)^i - 1$ so that:

$$\frac{\pi_s - C}{1 - C} \geq \frac{\left(1 + (1+r)^i - 1\right)^j}{(1 + (1+r)^i - 1\,)^j - \delta^j}$$

$$\pi_s \geq \frac{\left((1+r)^i\right)^j * 1 - C}{((1+r)^i)^j - \delta^j} + C$$

$$\pi_s \geq \frac{(1+r)^n * (1-C)}{(1+r)^n - \delta^j} + C$$

The condition of indifference between long-term contracts and one-year term is estimated:

$$\frac{(1+r)^n * (1-C)}{(1+r)^n - \delta^j} + C \geq \frac{(1+r)^n}{(1+r)^n - \lambda^n}$$

$$\frac{(1+r)^n - \delta^j * C}{(1+r)^n - \delta^j} \geq \frac{1}{1 - \frac{\lambda^n}{(1+r)^n}}$$

$$(1 - \frac{\lambda^n}{(1+r)^n}) * \left((1+r)^n - \delta^j * C\right) \geq (1+r)^n - \delta^j$$

$$\left(-C + \frac{\lambda^n * C}{(1+r)^n} + 1\right) \delta^j \geq \lambda^n$$

$$\delta^{j-1} \geq \frac{\lambda^n}{-C + \frac{\lambda^n * C}{(1+r)^n} + 1}$$

$$\delta \geq \left(\frac{\lambda^n}{-C + \frac{\lambda^n * C}{(1+r)^n} + 1}\right)^{\frac{1}{j}}$$