DEFORESTATION AND AGRICULTURE

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Abstract

This paper investigates the factors influencing land use decisions and establishes conditions for the optimal allocation of agricultural and forest lands in an economy using a dynamic equilibrium model and simulation exercises. Steady state results that the optimal land use decision is influenced by the discount rate, land productivity, rates of return on capital and labor, and society's preferences for consumption. Through comparative static analysis, the study identifies the conditions under which the environmental Kuznets curve (EKC) for deforestation can emerge. The comparative statics results indicate that an EKC for deforestation will occur when land productivity and the preference for environmental services from forest land reach critical levels. Unlike previous studies that focused on population pressure and other structural factors, this study highlights the significance of agricultural and resource productivity growth in driving the emergence of the EKC deforestation relationship. The theoretical analysis is supported by simulation models, which indicate that changes in the preference weighting value significantly impact the level of deforestation in an economy. Overall, within the specified short-run parameter ranges, a substantial portion of land is allocated to agricultural production.

Introduction

Forest contributes to national income and its protection (or destruction) is a factor in the nation's overall economic development. The current pace of loss of tropical forest is closely related to past developmental processes and institutional and structural factors in the tropical economies (Walker (1993)). Therefore, the forest conversion process is an outcome of economic decision-making by farmers, the logging industry, state agencies, and others. This paper explores the underlying theoretical relationship between deforestation and several other variables, such as discount rate, land productivity, and population growth, using a dynamic equilibrium model. It then validates the finding from the theoretical model with simulation results.

Objectives

The objectives of this study are to examine the dynamics of the deforestation process in an economy and an analysis of the relationship between agricultural productivity growth and forest land cover changes.

Methods

The utility function of the island people can be written as:

$$u_t = u(c_t, z_t)$$

where,
c_t = consumption of output product from the farming sector, and
z_t = environmental service value of the forest resources.
For the sake of simplic[...] he harvesting cost of the forest equals the marketable. income derived from th[...]er; i.e., there is no other use of timber in this economy. Thus, the forest is harvested only to clear land for agricultural production. Assume there is no other tangible income from the forest sector. This restriction will not adversely affect the optimum allocation of resources Now assume that the representative individual lives forever, where the preferences of the representative agent are represented by:

$$\sum_{t=0}^{\infty} \beta^t (\lambda ln c_t + (1-\lambda) ln z_t)$$

where $\beta = 1/(1+\delta)$ is the individual's subjective discount factor, $0 < \beta < 1$, and λ = individual's Pareto weight on the pr[...]onsumption of goods and services, $0 < \lambda < 1$. This type of infinite generat[...] model is selected to consider the intergenerational aspect of utilizing both the consu[...] environmental services use of the forest's resources

Aggregate Social Welfare Function:

$$\max_{\{c_t, z_t\}} \sum_{t=0}^{\infty} \beta^t (\lambda ln C_t + (1-\lambda) ln Z_t)$$

Agricultural Production Function:

$$Y_t = A^t K_t^{\alpha} L_t^{\varpi} X_t^{\gamma}$$

where,
Y_t = aggregate level of farming output in time t;
K_t = capital available at time t;
L_t = labor force available at time, which grows at the rate of n percent per year, i.e.,

$$\left(\frac{L_{t+1}}{L_t}\right) = (1+n);$$

Dynamics of Agricultural land: X_t [...]nd in time period t is $1 - X_t$

$$\max_{\{K_{t+1}, u_t\}} \sum_{t=0}^{\infty} \beta^t \{\lambda ln(A^t K_t^{\alpha} L_t^{\varpi}(X_{t-1}+u_t)^{\gamma} - K_{t+1}) + (1-\lambda) ln(\theta(1 - X_{t-1} - u_t))\}$$

Subject to the flow of deforestation constant shown as

$$X_t = X_{t-1} + u_t.$$

About the Authors and Disclaimer

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Comparative Statics

In the steady-state condition, capital, consumption, and output all grow at the same rate as the prevailing interest rate in the economy. Assuming a zero transaction cost world where the savings rate is equal to the interest rate, and substituting for s in equation (16) by the interest rate in the economy, which is equal to the consumption growth rate, the equilibrium agricultural land acreage in the economy becomes

$$X_t^* = \frac{\lambda\gamma}{(\lambda\gamma + (1-\lambda)\{A(1+n)^{\varpi}\}^{\frac{1}{1-\alpha}}}$$

Since all the right hand side variables are constant, $\boldsymbol{X_t^* = X^*}$

1. *Effect of subjective discount rate on deforestation:* Results of this study hold when $\frac{\partial X_t^*}{\partial \delta} \geq 0$ or $\frac{\partial X_t^*}{\partial \beta} \leq 0$ and when certain other parameter constraints hold steady. The steady state value in equation (20) indicates that as the discount rate increases in an economy, more forest area would be harvested to meet immediate consumption needs. This result is consistent with the forest harvesting decision solution of Samuelson (1976).

2. *Effect of land productivity:* In relation to the land productivity and deforestation decision, with optimal condition $X_t = X_t^*$ from equation (11)

$$\frac{\lambda\gamma A^t K_t^{\alpha} L_t^{\varpi}(X_{t-1}+u_t)^{\gamma-1}}{C_t} = \frac{(1-\lambda)}{(1-X_t)} \quad \text{let} \quad G = \frac{(1-\lambda)C_t}{\lambda A^t K_t^{\alpha} L_t^{\varpi}}$$

$$\gamma X_t^{\gamma-1} = \frac{G}{(1-X_t)}$$

$$X_t^{\gamma-1} + \gamma(\gamma-1)X_t^{\gamma-2}\frac{\partial X_t}{\partial \gamma} = G\frac{\partial X_t}{\partial \gamma}$$

$$\frac{\partial X_t}{\partial \gamma}(\gamma(\gamma-1)X_t^{\gamma-2} - G) = -X_t^{\gamma-1}$$

this study offers two alternate scenario, $\frac{\partial X_t^*}{\partial \gamma} \geq 0$ if $\gamma \leq 1$, and $\frac{\partial X_t^*}{\partial \gamma} \leq 0$ if $\gamma \geq 1$. This means that as land productivity grows, larger forest areas will be converted to farming as long as $\gamma \leq 1$. However, once the land productivity increases to sufficiently high levels, i.e., when $\gamma \geq 1$, then further improvement in the productivity would reverse the deforestation trend, thus producing a lower deforestation rate. This switch of parameter value of γ is a critical relationship for the emergence of the EKC for deforestation.

3. *Effect of capital productivity:* From equation (20), we can state the condition that $\frac{\partial X_t^*}{\partial \alpha} \geq 0$. This implies that if capital productivity grows in an economy, then more land is needed for farming purposes, *ceteris paribus*. Therefore, larger forest areas would be mined as capital productivity grows. This result implies that the net effect of improvement in the aggregate level of productivity in the farming sector depends on whether it originates from the improvement of land productivity or from capital productivity.

4. *Effect of the changes on social planner's preference:* From the equation (20), with the condition that $\frac{\partial X_t^*}{\partial \lambda} \geq 0$, we find that the level of deforestation depends on society's preferences for consumption of outputs from farming versus environmental services derived from the forests. The more weight the society gives to farming outputs, the larger proportion of wild forest area will be converted to farming. This result is consistent with economic theory of natural resource conservation. Considering the environmental goods and services as luxury goods, the value of λ also changes in the economy as income increases. This is consistent with changing preferences of the agent as income rises and the emergence of the EKC relationship in the economy.

5. Effect of population growth: From equation (20), $\frac{\partial X_t^*}{\partial n} > 0$, or $\frac{\partial X_t^*}{\partial n} < 0$, depending on the values of several model parameters. As opposed to the Malthusian view that population growth always destroys the forest land (Myers (1994) and Ehrlich and Ehrlich (1997)), this study's results show that the net impact of population growth on deforestation actually depends on the technology A, the capital productivity (α) and labor productivity (ϖ) in the economy. There is no clear cut line that population growth always leads to deforestation. Rather, the deforestation rate depends upon a range of other factors as well as population. Several empirical studies have also demonstrated this (Bhattarai and Hammig (2001); Barbier and Burgess (2001); Brown et al. (1994)).

6. Effect of the overall technology available: From the equation (16), we find that $\frac{\partial X_t^*}{\partial A^t} > 0$ or $\frac{\partial X_t^*}{\partial A^t} < 0$ depending upon whether $A > 0$ or $A < 0$. As a result, if the overall production technology (A) is more than one, implying increasing returns to technology (Romer 1986), then improvements in overall production technology will reduce the land conversion of forest and enhance the preservation of forest land.

The above comparative statics conditions show that there is no a priori rationale to suggest that forests will be continuously mined as societal income increases. The relationship between deforestation levels and societal income at any time depends upon several other characteristics of the economy and values of other parameters, as noted above. These include change in land productivity (γ), available technology (A^t), social planner's Pareto weight (λ), and society's subjective discount factors (δ and β). From the above analysis, and from equation(11)

$$\frac{\lambda\gamma A^t K_t^{\alpha} L_t^{\varpi}(X_{t-1}+u_t)^{\gamma-1}}{C_t} = \frac{(1-\lambda)}{(1-X_t)} \quad \text{and let} \quad Q = \frac{(1-\lambda)C_t}{\lambda\gamma A^t L_t^{\varpi}}$$

$$(X_{t-1}+u_t)^{\gamma-1}(1-X_t) = \frac{Q}{K_t^{\alpha}}$$

$$\frac{\partial u_t}{\partial K_t} X_t^{\gamma-1}\left((\gamma-1)\frac{(1-X_t)}{X_t} - 1\right) = -\alpha Q K_t^{-\alpha-1} \quad \text{here} \quad 0 < X_t < 1$$

This study infers that during the early stage of development, when the land productivity, capital productivity and labor productivity all are less than one, then $\frac{\partial u_t^*}{\partial K_t} > 0$, where u_t^* is the deforestation level in time t. But, once the societal income increases to a sufficiently high level, this condition changes to $\frac{\partial u_t^*}{\partial K_t} < 0$ due to changes in underlying parameter values for productivity, land, labor and capital, as well as changes in societal preferences for goods and services. All of these contribute to the emergence of the EKC for deforestation in the economy.

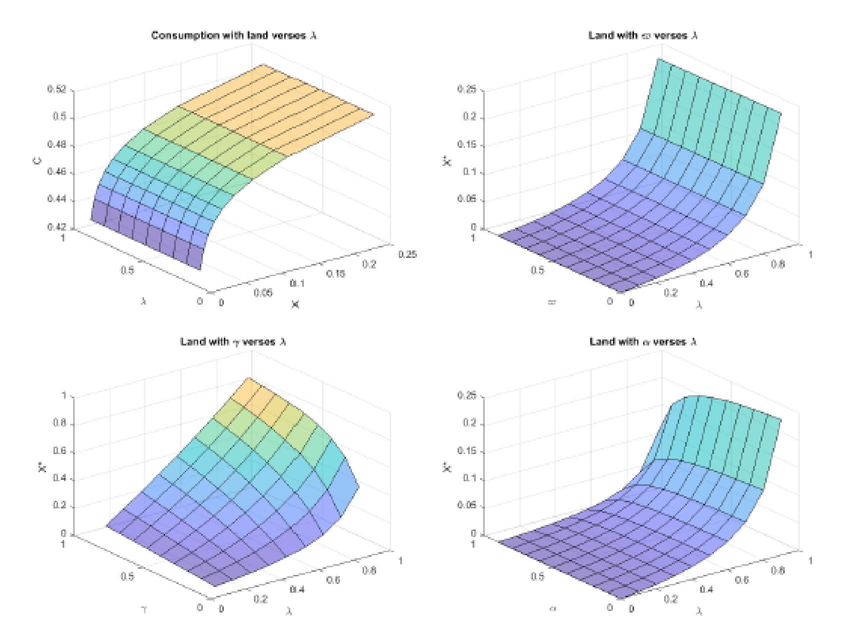

Figure 1: With $A = 1.1$, $\gamma = 0.04$, $\varpi = 0.04$, $\alpha = 0.01$, $s = 0.02$, and $n = 0.02$, followings are the graphs plotted from consumption (C) of equation (9) and change of equilibrium agricultural land X^* of equation (20) with respect to the parameters λ, and γ, ϖ as well as α. The figure of the first row left represents the value of consumption C and agricultural land X with respect to the change of individual Pareto weight value $0 < \lambda < 1$. The figure of the first row right represents the change in the value of X^* with respect to $0 < \varpi < 1$ and $0 < \lambda < 1$, the figure of the second row left is the change of X^* with respect to $0 < \gamma < 1$ and $0 < \lambda < 1$, the figure of the second row right is the change of X^* with respect to $0 < \alpha < 1$ and $0 < \lambda < 1$, and all other parameters are taken as given above.

Comparative Dynamics

The comparative dynamics uncovers the cumulative effect of the parameter value of capital, labor, and agricultural land, as well as changes in societal preferences for goods and services in the optimal function. The first partial of the optimal function recovers the cumulative discounted function, and the second partial recovers the path of the discounted function over a long period of time. While reviewing the history of the study of comparative statics and comparative dynamics, Samuelson (1965) and Silberberg (1974) are the founder of comparative statics, and Caputo (1990) and Oniki (1973) contribute different types of calculation to work on the comparative dynamics depending upon autonomous, non-autonomous, and time horizon of the optimal control problem. Later, Benchekroun (2008); Caputo and Ling (2017) and Ling (2022) applied the idea of comparative dynamics to study
in economics, agriculture, and game theory. The previous section of comparative statics focuses on the change of equilibrium land with respect to the changes in related parameters. However, those changes do not address the changes of the social planner with respect to the parameters in a long-term time-dependent situation. For the sake of a complete study of the dynamics of the
effect of deforestation on the economy, the comparative statics of the previous section is extended to analyze the comparative dynamics of the non-autonomous form of the objective function of the social planner using the idea of Caputo (1990).

The optimal function,

$$H = \beta^t\{\lambda ln(A^t K_t^{\alpha} L_t^{\varpi}(X_{t-1}+u_t)^{\gamma} - K_{t+1}) + (1-\lambda) ln(\theta(1 - X_{t-1} - u_t)\} + \mu_1(X_t - X_{t-1} - u_t) \quad (21)$$

Optimizing the Hamiltonian (21) with respect to parameters $\mathbf{p} = (\beta, \alpha, \varpi, \gamma, \lambda, \theta)$, the corresponding optimal path are

$$J_{\beta}(\mathbf{p}) = \int_0^{\infty} \frac{t}{\beta}\beta^t\{\lambda ln(A^t K_t^{\alpha} L_t^{\varpi}(X_{t-1}+u_t)^{\gamma} - K_{t+1}) + (1-\lambda) ln(Z_t)\}dt > 0 \quad (22)$$

$$J_{\alpha}(\mathbf{p}) = \int_0^{\infty} \beta^t \frac{\lambda\alpha A^t K_t^{\alpha-1} L_t^{\varpi}(X_{t-1}+u_t)^{\gamma}}{(A^t K_t^{\alpha} L_t^{\varpi}(X_{t-1}+u_t)^{\gamma} - K_{t+1})} > 0 \quad (23)$$

$$J_{\varpi}(\mathbf{p}) = \int_0^{\infty} \beta^t \frac{\lambda\varpi A^t K_t^{\alpha} L_t^{\varpi-1}(X_{t-1}+u_t)^{\gamma}}{(A^t K_t^{\alpha} L_t^{\varpi}(X_{t-1}+u_t)^{\gamma} - K_{t+1})} > 0 \quad (24)$$

$$J_{\gamma}(\mathbf{p}) = \int_0^{\infty} \beta^t \frac{\lambda\gamma A^t K_t^{\alpha} L_t^{\varpi}(X_{t-1}+u_t)^{\gamma-1}}{(A^t K_t^{\alpha} L_t^{\varpi}(X_{t-1}+u_t)^{\gamma} - K_{t+1})} > 0 \quad (25)$$

$$J_{\lambda}(\mathbf{p}) = \int_0^{\infty} \beta^t (ln(A^t K_t^{\alpha} L_t^{\varpi}(X_{t-1}+u_t)^{\gamma} - K_{t+1}) - ln(\theta(1 - X_{t-1} - u_t))dt > 0 \quad \text{if} \quad C_t > Z_t > 1$$

$$J_{\beta\beta}(\mathbf{p}) = \int_0^{\infty} \frac{t^2}{\beta^2}\beta^t\{\lambda ln(A^t K_t^{\alpha} L_t^{\varpi}(X_{t-1}+u_t)^{\gamma} - K_{t+1}) + (1-\lambda) ln(Z_t)\}dt > 0 \quad \text{if} \quad C_t > 1 \quad \text{and} \quad Z_t > 1$$

Symmetry

$$J_{\alpha\varpi}(\mathbf{p}) = J_{\varpi\alpha}(\mathbf{p})$$
$$J_{\alpha\gamma}(\mathbf{p}) = J_{\gamma\alpha}(\mathbf{p})$$
$$J_{\varpi\gamma}(\mathbf{p}) = J_{\gamma\varpi}(\mathbf{p})$$

Conclusions

The comparative statics analysis of this study suggests us that the optimum land use in the steady state condition of an economy is affected by the discount rate, land productivity, the rate of return on capital, and society's preferences over consumption of outputs from farming versus outputs produced from forest land. The results from the comparative statistics analysis also confirm the likelihood of an EKC for deforestation, as illustrated by several previous studies of cross-country empirical analyses on the topic. In other words, the EKC deforestation relationship emerges in an economy when the land productivity and the preference (i.e., income elasticity) of the environmental services from forest land reach a critical level. The comparative statics analysis provides an illustration of alternative conditions under which the EKC for deforestation emerges, or is absent, in the economy, and the specific limitations of this process. The results from inter-temporal dynamic modeling also validate the existence of the EKC deforestation relationship.

Unlike previous studies of the EKC for deforestation, this study tests for a Kuznet-type relationship for deforestation using the basic structure of the economy and adopting an inter-temporal dynamic equilibrium framework of analysis. The use of inter-temporal dynamic equilibrium modeling is particularly important here due to the fact that forest use is an investment decision within a long-run decision-making process.

Furthermore, the comparative dynamics analysis of this study shows that the optimal path is affected by parameters over the long term. The weight of capital (α), labor (ϖ), and land used (γ) show an EKC behavior. These parameters show a symmetry behavior with each other as well.