



AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
<http://ageconsearch.umn.edu>
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

Integrated economy of humans and biological resources: A general equilibrium approach

Liaila Tajibaeva

Selected Paper prepared for presentation at the American Agricultural Economics
Association Annual Meeting,
Providence, Rhode Island, July 24-27, 2005

Abstract: This paper develops a model of economic growth where a natural resource is an important part of the economy. In the environment of labor and capital markets and an open access resource stock the general equilibrium approach allows for the endogenous prices and consumption, as well as labor allocation between employment and harvest of the resource for own consumption. Equilibrium for the model is defined and characterized. The analysis of steady state and approach dynamics show that if an economy has a high capital stock and high employment then it can converge to a steady state without depleting an open access resource stock. However, if an economy has low capital stock and low employment then it can deplete its resource stock.

Keywords: open access resource, natural resource, economic growth, approach dynamics, endogenous prices, endogenous consumption and labor allocation.

The author's contact information and affiliation: Department of Applied Economics, University of Minnesota, 1994 Buford Avenue, 316, St Paul MN 55108, telephone 612-625-5719, fax 612-625-2729, e-mail taji0004@umn.edu

Copyright 2005 by Liaila Tajibaeva. All rights reserved. Readers may make verbatim copies of this document for non-commercial purposes by any means, provided that this copyright notice appears on all such copies.

1 Introduction

An integrated interaction of the economy and the environment is inherent to any human society. This interaction is more pronounced in a low-income community where natural resources are the main source of people’s livelihoods and people depend directly on the local environment to provide them with food and medicine, building and cooking materials, grazing pastures and other resources and services.

At the same time, a low-income country often has markets that do not function well. Incomplete or vaguely defined property rights may encourage over-use of resources. For example, open access to a resource that allows anyone to use it creates incentives for overexploitation of that resource (“tragedy of the commons”). Dependency on resources combined with inadequate institutions may create incentives that deplete resources, which deepens poverty thus creating a downward cycle.

Given the above considerations, how do imperfect markets affect the growth of a low-income country that is dependent on its biological resources? What are the best economic policies to promote improvement of the welfare of that country?

To answer these questions, this research develops a theoretical framework and analyses it analytically. Developing a theoretical framework first entails unifying the economic equilibrium theory and biology modeling techniques into a unified dynamic model. Second, by incorporating the lack of the natural resource property rights into this framework this research expands a conventional economic growth model to make it more applicable to analyzing a low-income economy.

Most of the prior literature addresses questions of economic growth, resource use, and property rights or other institutional questions separately. Only recently have there been attempts to combine economic and biological understanding into a comprehensive economic model that addresses the necessities of the modern-day low-income countries. This is where this research contributes to the literature. It further develops the framework of the unified bio-economic model with endogenous prices and consumption, labor allocation, and harvest

decisions. It defines and characterizes an equilibrium for this model, as well as analyses steady state and approach dynamics.

In the recent literature that combines biology modeling and economics equilibrium price theory, Brock and Xepapadeas (2002) develop an approach to unify equilibrium price theory with Tilman ecological modeling to prove the existence of a price equilibrium for a stochastic discrete choice model of resource-based species competition. Pascual and Hilborn (1995) and Barrett and Arcese (1998) conduct a more applied research that develops a model that uses elaborately estimated biology resource equations but treat economics harvesting decisions as exogenously given. Pascual and Hilborn (1995) focus more on the effects of alternative harvesting strategies on the wildebeest population within a Bayesian decision setting. While Barrett and Arcese (1998) use the wildebeest population dynamics model developed by Pascual and Hilborn (1995), and build onto it to explore the interactions of wildlife populations and human consumption behavior when labor and product markets are imperfect.

Liobooki et al (2002) investigate the relationship between illegal hunting and income. They demonstrate how ownership of livestock, demographics, and community programs affect illegal hunting. Illegal hunting is also induced by the common property nature of the natural resources. An open access form of ownership creates incentives to overuse a resource and each additional individual using it creates a negative externality on all other users of this resource (Dasgupta and Maler, 1995). This in turn can create a cycle, in which over-exploited agricultural soils, pastures, fisheries, forests, and water resources result in even smaller economic gains. However, a household may not even implement a sustainable resource management of a privately owned resource. Reardon and Vosti (1995) examine the ability and willingness of rural households to implement sustainable natural resource management. They denote by “welfare poverty” the inability to meet basic human food, shelter, and clothing needs, while they denote by “investment poverty” the inability to carry out sustainable natural resource management even when there is adequate wealth to prevent

welfare poverty. They also note that even though the capacity for capital-led investment is necessary for households to invest in sustainable natural resource management, it is not sufficient, because imperfect markets may prevent conversion of assets from one form to another (Swinton and Escobar, 2003).

In the next section I will develop the unified model that incorporates economic growth and natural resource theory, define and characterize an equilibrium for that model. Section 3, solves for and analyses steady state and approach dynamics, and discusses the results for low-income resource-dependent economies. Section 4 concludes by defining the next steps for this research.

2 Model

2.1 Environment

The purpose of this section is to derive a simple model that represents an integrated economy of humans and biological resources. This model draws from the economic growth model of Ramsey (1938), Cass (1965), and Koopmans (1965) and combines it with the theory of dynamic resources in continuous-time as reviewed by Conrad and Clark (1987).

There are I infinitely lived households, denoted by $i = 1, \dots, I$. All households are identical in their preferences and initial endowments. The households maximize their preferences over two commodities that are a consumption good c and some good b that is harvested from the wildlife. The wildlife is the biological resource. For example, the wildlife can be wild-animals, a household hunts it and consumers wildlife meat. The preferences are continuously discounted over time t by the household time-preference parameter, denoted by δ . Household preferences take a form of a utility function $u(c, b)$, where $u : \mathbb{R}_+^2 \rightarrow \mathbb{R}$ is a continuous function.

There are three factors of production that are labor, capital, and the biological resource. The households have the initial endowment of labor \mathcal{L} and capital k_0 . The households

allocate their labor endowment between spending l amount of labor working in a consumption good sector and earning the wage rate w and spending the remaining $\mathcal{L} - l$ amount of labor harvesting wildlife for their own consumption. The additions to the capital stock k , are achieved by investing some of the consumption good. The households do capital accumulation and rent their capital k to the consumption good sector at the rental rate of r . Over time capital depreciates at the rate φ .

There is an initial stock of the biological resource B_0 . Nobody owns this resource. Undefined property rights may encourage over-use of this resource. In addition, the resource harvest exerts negative externalities and may distort the labor market. The size of this open access biological resource stock at time t is denoted by $B(t)$. In the absence of harvesting, the net density dependent dynamics of the resource is described by the difference equation $\dot{B} = F(B(t))$. Where the growth function $F : \mathbb{R}_+ \rightarrow \mathbb{R}_+$ and there exists an interval $[\underline{B}, \bar{B}]$ for some $\underline{B} \geq 0$, such that $F(B) > 0$ for $\underline{B} < B < \bar{B}$ and $F(B) < 0$ for $B \geq \bar{B}$.

The households are also endowed with a harvest technology that transforms the biological resource into a commodity. The rate of harvest $b(t)$ of the renewable resource per unit time is a function of an economic input of labor that is devoted to harvesting and is denoted by $\mathcal{L} - l(t)$, and of the available stock $B(t)$. The harvest function is $b(t) = H(\mathcal{L} - l(t), B(t))$, where the rate of harvest $b(t)$ is measured in the same units as the resource stock $B(t)$ and $H : \mathbb{R}_+^2 \rightarrow \mathbb{R}_+$. Assume that H is increasing in both labor $\mathcal{L} - l(t)$ and available stock $B(t)$. With harvest, the rate of change of the resource stock includes both growth and harvest and the resource difference equation becomes $\dot{B} = F(B(t)) - b(t)$.

In the consumption good sector there exists a CRS technology that converts labor, L , and capital, K , into a consumption good. This technology is represented by function $f(L, K)$ where $f : \mathbb{R}_+^2 \rightarrow \mathbb{R}_+$. Given the above assumptions, a firm's maximization problem can be written as follows:

$$\max_{L(t), K(t) \geq 0} p(t) f(L(t), K(t)) - w(t) L(t) - r(t) K(t).$$

This states that the firm maximizes its revenues from the consumption good sales minus its labor and capital factor-cost, where p is the price of the consumption good.

Given the above assumptions, a representative household's problem can be written as follows:

$$\max_{c(t), l(t), k(t)} \int_0^\infty e^{-\delta t} u(c(t), b(t)) dt$$

such that

$$b(t) = H(\mathcal{L} - l(t), B(t)) \quad (1)$$

$$\dot{k} = \frac{w(t)}{p(t)} l(t) + \frac{r(t)}{p(t)} k(t) - \varphi k(t) - c(t) \quad (2)$$

$$c(t), k(t) \geq 0 \quad (3)$$

$$0 \leq l(t) \leq \mathcal{L} \quad (4)$$

k_0 given.

Condition 1 states the harvest technology of the labor and resource factors. Condition 2 states that the consumption good and investment expenditure equals the wage and capital rental income. This condition includes the capital growth that is equal investment minus capital depreciation. Condition 3 is a non-negativity constraint on the consumption good and the capital stock. Condition 4 is a non-negativity of labor allocation between harvest and wage earnings within a labor endowment.

2.2 Equilibrium

Given the above description of the economy, the firm's problem and simplified household's problem where the harvest technology condition 1 is substituted for the consumption of commodity b , define an equilibrium as follows:

Definition 1 Allocation $\{c(t), l(t), k(t), L(t), K(t), B(t)\}$ and a price system

$\{p(t), w(t), r(t)\}$ constitute an equilibrium if

1. Given prices, allocation $\{c(t), l(t), k(t)\}$ maximizes household preferences subject to its budget

$$\begin{aligned} \max_{c(t), l(t), k(t)} \quad & \int_0^\infty e^{-\delta t} u(c(t), H(\mathcal{L} - l(t), B(t))) \, dt \\ \text{such that} \quad & \\ \dot{k} = \frac{w(t)}{p(t)} l(t) + \frac{r(t)}{p(t)} k(t) - \varphi k(t) - c(t) \quad & \\ c(t), k(t) \geq 0 \quad & \\ 0 \leq l(t) \leq \mathcal{L} \quad & \\ k_0 \text{ given,} \quad & \end{aligned}$$

2. Given prices, allocation $\{L(t), K(t)\}$ maximizes profits

$$\max_{L(t), K(t) \geq 0} p(t) f(L(t), K(t)) - w(t) L(t) - r(t) K(t),$$

3. The resource

$$\dot{B} = F(B(t)) - H(\mathcal{L} - l(t), B(t)), \quad (5)$$

4. Markets clear

$$c(t) + \dot{k} + \varphi k(t) = f(L(t), K(t)) \quad (6)$$

$$l(t) = L(t) \quad (7)$$

$$k(t) = K(t). \quad (8)$$

Condition 5 states that the change in the resource stock equals the natural resource growth minus harvest. Condition 6 states that the total production of the final good equals consumption plus investment. Condition 7 states that the amount of labor supplied by the households, l , equals the amount of labor employed by the firm, L . Condition 8 states that the amount of capital supplied by the households, k , equals the amount of capital rented by the firm, K .

2.3 Characterization of an equilibrium

To simplify notation omit the time reference (t). The current-value Hamiltonian for the representative consumer's problem is

$$\mathcal{H}(c, l, k; \mu) = u(c, H(\mathcal{L} - l, B)) + \mu \left[\frac{w}{p}l + \frac{r}{p}k - \varphi k - c \right]$$

and the necessary conditions of the maximum principle along with the transversality condition are:

$$u_c = \mu \tag{9a}$$

$$- u_H H_l = \mu \frac{w}{p} \tag{9b}$$

$$\mu \left(\delta + \varphi - \frac{r}{p} \right) = \dot{\mu} \tag{9c}$$

$$\dot{k} = \frac{w}{p}l + \frac{r}{p}k - \varphi k - c \tag{9d}$$

$$\lim_{t \rightarrow \infty} k\mu = 0, \tag{9e}$$

where u_c and u_H are partial derivatives of the utility function with respect to consumption c and harvest H respectively, and H_l is the partial derivative of the harvest function with respect to labor l . Time-differentiation of equations 9a and 9b and substitution into equation 9c establishes the time difference equations for consumption and labor in prices for the

representative consumer's problem¹:

$$\dot{c} = \frac{u_c}{u_{cc}} \left(\delta + \varphi - \frac{r}{p} \right), \quad (10)$$

where u_{cc} is the second order partial derivative of the utility function with respect to consumption c , and

$$\dot{l} = \frac{H_l \left(u_H - \frac{u_{Hc}}{u_{cc}} u_c \right) \left(\delta + \varphi - \frac{r}{p} \right)}{u_{HH} H_l^2 + u_H H_{ll}}, \quad (11)$$

where u_{Hc} and u_{HH} and the second order partial derivatives of the utility function with respect to harvest H and consumption c , and to harvest H and harvest H , respectively; and H_l is the first order partial derivative.

Next, the firm's profit maximization problem with the CRS production function establishes that the labor wage and the capital rental rate are:

$$\begin{aligned} \frac{w}{p} &= f_L \\ \frac{r}{p} &= f_K, \end{aligned}$$

and

$$f(L, K) = f_L L + f_K K,$$

where f_L and f_K are the partial derivatives of the production function with respect to labor L and capital K respectively.

By using the market clearing condition 7 for labor and condition 8 for capital, and substituting for prices into the household's consumption equation 10 and labor equation 11 derive the equilibrium equations of motion for consumption, \dot{c} , and labor, \dot{l} . By using market

¹ $u_{cc}\dot{c} = \dot{\mu}$ and $-u_{Hc}\dot{c}H_l - (u_{HH}H_l^2 + u_H H_{ll})\dot{l} = \dot{\mu}\frac{w}{p}$ are the time derivatives of equations 9a and 9b respectively.

clearing condition 6 for a consumption good and investment, household budget equation 9d, and the wildlife equation of motion 5 derive the equilibrium equations of motion for capital, \dot{k} , and resource, \dot{B} . Then the following equations of motion for consumption, labor, capital, and resource characterize an equilibrium:

$$\dot{c} = \frac{u_c}{u_{cc}} (\delta + \varphi - f_k) \quad (12a)$$

$$\dot{l} = \frac{H_l \left(u_H - \frac{u_{Hc}}{u_{cc}} u_c \right) (\delta + \varphi - f_k)}{u_{HH} H_l^2 + u_H H_{ll}} \quad (12b)$$

$$\dot{k} = f(l, k) - \varphi k - c \quad (12c)$$

$$\dot{B} = F(B) - H(\mathcal{L} - l, B). \quad (12d)$$

3 Steady state and approach dynamics analysis

To analyze the steady state and approach dynamics assume that the utility function is quasilinear in harvest, $u(c, b) = \ln c + b$. The harvest is a Cobb-Douglas technology, $H(\mathcal{L} - l, B) = (\mathcal{L} - l)^\gamma B^{1-\gamma}$, where γ is the labor share in harvest. The consumption and investment good technology is CRS, $f(l, k) = l^\theta k^{1-\theta}$, where θ is the share of labor in production. The resource growth function is logistic with the growth equation $F(B) = sB \left(1 - \frac{B}{\xi} \right)$ where s is the intrinsic growth rate and ξ is the environmental carrying capacity.

3.1 Steady state

To find a steady state, the first step is to solve for the above functional forms equations of motion, 12a, 12b, 12c, and 12d, that characterize an equilibrium, and the second step is to set these equations of motion equal to zero. In the first step, given a quasilinear utility function, substitute for consumption. Then follow the steps outlined in the previous section

of characterizing an equilibrium to find the labor, capital, and resource equations of motion:

$$\begin{aligned} \dot{l} &= \frac{\mathcal{L} - l}{\gamma - 1} [(1 - \theta) l^\theta k^{-\theta} - \varphi - \delta] \\ \dot{k} &= k \left[l^\theta k^{-\theta} \left(1 - \frac{\theta}{\gamma} \frac{1}{l} \left(\frac{\mathcal{L} - l}{B} \right)^{1-\gamma} \right) - \varphi \right] \\ \dot{B} &= B \left[s \left(1 - \frac{B}{\xi} \right) - \left(\frac{\mathcal{L} - l}{B} \right)^\gamma \right], \end{aligned}$$

where consumption is a function of labor, capital, and resource:

$$c = \theta l^\theta k^{1-\theta} \frac{1}{\gamma} \left(\frac{\mathcal{L} - l}{B} \right)^{1-\gamma}.$$

In the second step, in the steady state $\dot{l} = \dot{k} = \dot{B} = 0$. This implies that

$$\dot{l} = 0 \Rightarrow l = \mathcal{L} \text{ or } k = l \left(\frac{1 - \theta}{\varphi + \delta} \right)^{1/\theta} \quad (13a)$$

$$\dot{k} = 0 \Rightarrow k = l \left(\frac{1}{\varphi} \right)^{1/\theta} \left[1 - \frac{\theta}{\gamma} \frac{1}{l} \left(\frac{\mathcal{L} - l}{B} \right)^{1-\gamma} \right]^{1/\theta} \quad (13b)$$

$$\dot{B} = 0 \Rightarrow l = \mathcal{L} - B s^{1/\gamma} \left(1 - \frac{B}{\xi} \right)^{1/\gamma}. \quad (13c)$$

Condition 13a has two parts. I analyze each of them in turn. Suppose the first part holds, namely, in steady state $l_{ss} = \mathcal{L}$. This means that there is full employment. The households supply all of their labor endowment to the firm, and the firm hires it as a factor input in production of a consumption good. Consequently, the households do not allocate any labor to harvest the wildlife. Then condition 13c states that by this time the resource is either has already been depleted and the resource stock in steady state is $B_{ss} = 0$ or the resource stock is at its full carrying capacity $B_{ss} = \xi$. $B_{ss} = \xi$ happens when the opportunity cost of labor is high enough to keep full employment and to prevent households from allocating

any labor to harvest and from losing wages. By condition 13b, steady state capital stock is $k_{ss} = \mathcal{L} \left(\frac{1}{\varphi} \right)^{1/\theta}$. Graphically, this is the point $\left(\mathcal{L} \left(\frac{1}{\varphi} \right)^{1/\theta}, \mathcal{L} \right)$ in figure 2 and the points $(0, \mathcal{L})$ and (ξ, \mathcal{L}) in figure 3.

If the second part of condition 13a holds, then there are some $\tilde{l}, \tilde{k}, \tilde{B} > 0$ that solve equations 13a, 13b, and 13c. More specifically, from equation 13c labor l is a function of the resource stock B , $\tilde{l} = \mathcal{L} - \tilde{B} s^{1/\gamma} \left(1 - \frac{\tilde{B}}{\xi} \right)^{1/\gamma}$. Substituting this into equation 13a, capital is a function of the resource stock $\tilde{k} = \left[\mathcal{L} - \tilde{B} s^{1/\gamma} \left(1 - \frac{\tilde{B}}{\xi} \right)^{1/\gamma} \right] \left(\frac{1-\theta}{\varphi+\delta} \right)^{1/\theta}$. Substituting these expressions for labor and capital into equation 13b, gives an expression $g(\tilde{B}) = \mathcal{L}$ in the resource stock, where $g(\tilde{B}) = \tilde{B} s^{1/\gamma} \left(1 - \frac{\tilde{B}}{\xi} \right) + \frac{s^{1/\gamma-1}}{y} \left(1 - \frac{\tilde{B}}{\xi} \right)^{1/\gamma-1}$ and $y = \frac{\gamma}{\theta} \left[1 - \frac{\varphi(1-\theta)}{\varphi+\delta} \right]$. To find a steady state resource stock solve $g(\tilde{B}) = \mathcal{L}$ for \tilde{B} . Graphically, \tilde{B}_1 and \tilde{B}_2 are the solutions for a set of parameters to $g(\tilde{B}) = \mathcal{L}$ as depicted in figure 1. Substitute \tilde{B}_1 and \tilde{B}_2 to find the corresponding steady state labor allocation and capital stock, \tilde{l} and \tilde{k} respectively. Graphically, this is a point (\tilde{l}, \tilde{k}) of $\dot{l} = 0$ and $\dot{k} = 0$ intersection in figure 2 and the points (\tilde{B}_1, \tilde{l}) , (\tilde{B}_2, \tilde{l}) in figure 3.

3.2 Approach dynamics

The approach dynamics to the steady states exhibit three distinct traits, that are examined here in turn. The first case is when this economy starts with a high capital endowment and the high rate of employment. Graphically, these are the labor and capital combinations in the upper right and left corners above the $\dot{l} = 0$ and $\dot{k} = 0$ intersection in figure 2. In this case, the economy tends to employ even more labor and accumulate capital over time and thus moves towards the steady state point $\left(\mathcal{L} \left(\frac{1}{\varphi} \right)^{1/\theta}, \mathcal{L} \right)$. Consequently, if the economy starts with a resource stock, some \hat{B} , such that the initial labor employment, some \hat{l} , is above the minimum of the graph of $\dot{B} = 0$ in figure 3, that is \hat{l} is greater than the minimum of $\mathcal{L} - \hat{B} s^{1/\gamma} \left(1 - \frac{\hat{B}}{\xi} \right)^{1/\gamma}$, then the resource stock increases and in the steady state it is at its full carrying capacity, $B = \xi$. Otherwise, if the initial labor employment \hat{l} is below the minimum of $\dot{B} = 0$, then the resource stock decreases and is depleted in steady state, $B = 0$.

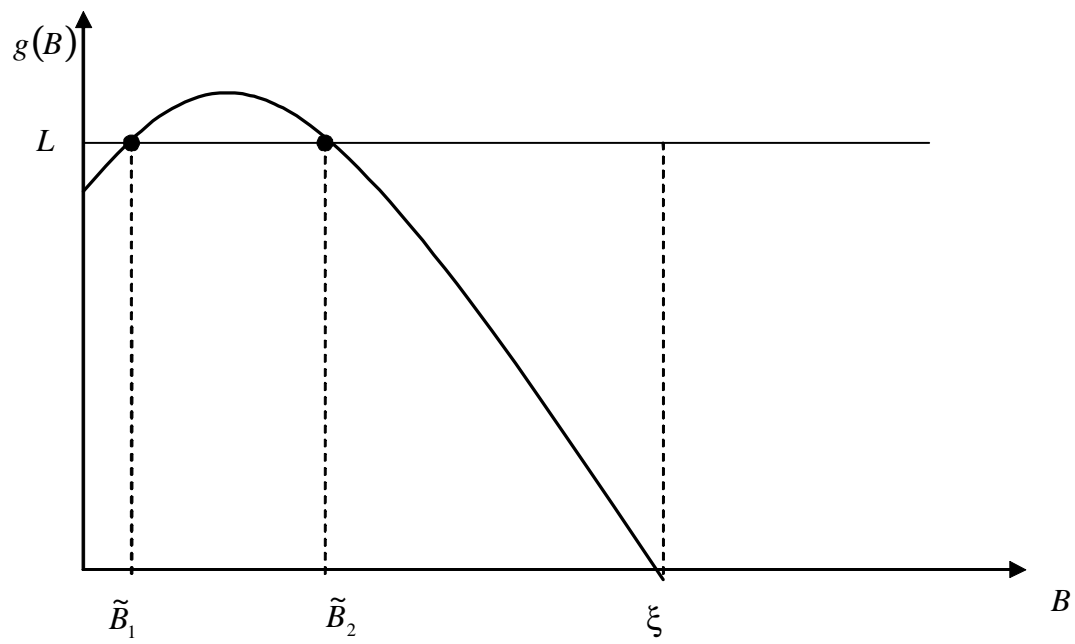


Figure 1: Solving for a resource stock by setting $g(B) = \mathcal{L}$

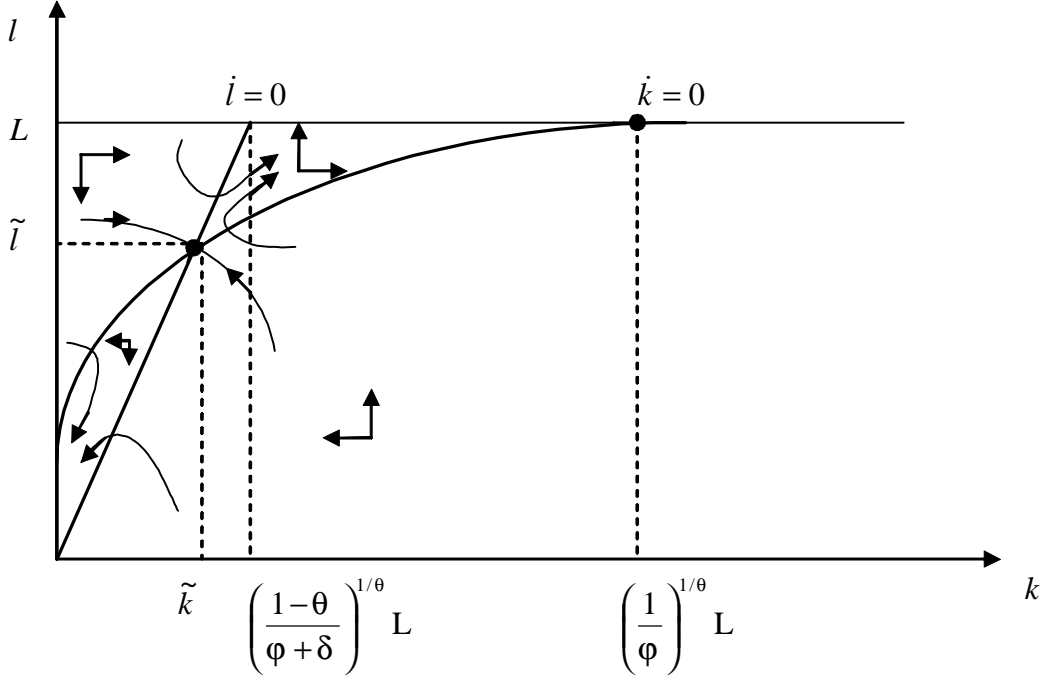


Figure 2: Phase diagram for $\dot{l} = 0$ and $\dot{k} = 0$

The second case is when this economy has some intermediate amount of capital and somewhat high employment rate on the convergence path depicted in figure 2. In this case the economy converges to the point (\tilde{l}, \tilde{k}) at the $\dot{l} = 0$ and $\dot{k} = 0$ intersection in figure 2 where $0 < \tilde{l} < \mathcal{L}$ and $0 < \tilde{k} < \left(\frac{1-\theta}{\varphi+\delta}\right)^{1/\theta}$. At this point some labor is supplied to the firm for labor wages, and some labor is allocated to harvesting the resource. The corresponding steady state resource stock is $0 < \tilde{B}_1 < \xi$.

The third case is when an economy starts with low capital stock and low employment. In this case, it 'sinks' to an even lower employment rate devoting more labor to harvesting the resource because of the low opportunity cost of lost wages. Graphically, this corresponds to the lower left corner in figure 2. Allocating more labor to harvest in turn reduces the amount of the final good, and thus of investment. It also reduces the resource stock. The rate of employment will continue to fall until it reaches the lowest possible unemployment

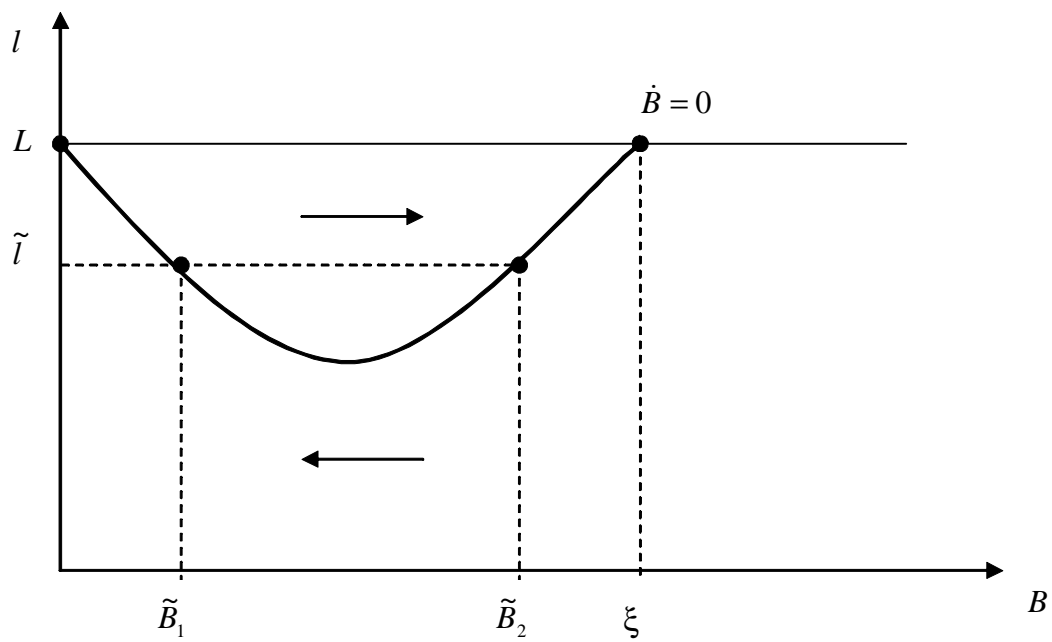


Figure 3: $\dot{B} = 0$

rate. This low bound on employment is strictly greater than zero, because at least some of the consumption good must be consumed by the households. The capital stock becomes smaller. Also, in turn an increased labor allocation to harvest drives the resource stock down as well, eventually at the risk of depleting the resource.

3.3 Discussion

The above analysis of the steady states and approach dynamics illustrates that in some cases, like in cases one and two, if an economy starts with high capital stock and high employment rate, it is possible for it to converge to a steady state with high employment, high capital stock, and an intact natural resource stock. That is, it is possible to avoid depleting the open access resource even without any resource regulation. Even though there is no direct cost of harvesting the resource, the resource is not depleted because there is an opportunity cost of labor that can be used elsewhere, earn wages, produce more of a consumption good that increases a household's utility. Thus, if this opportunity cost of labor is high enough, the households switch their labor allocation from harvest to this alternative wage income. For example, this can be a developed country. Graphically, it is in the upper right corner of the graph in figure 2. The households prefer to spend most of their time working for a wage, and allocate very little time for harvesting, like hunting wild animals. They instead buy the consumption goods from their wage income.

The above analysis also illustrates that in other cases, like in case three, if an economy starts with low capital stock and low employment, then this economy can 'sink' and allocate more labor to harvest because the opportunity cost of labor is low. This further reduces employment, depletes the resource, and reduces the capital stock. The economy is trapped in being poor. For example, this can be a low-income country. Graphically, it is in the lower left corner of the graph in figure 2. It has low capital stock and low employment. The opportunity cost of labor is low, so households allocate a lot of labor to harvest. Unless some economic policies take place, it remains a low-income country that depletes its natural

resource stock.

This suggests that a potential regulator needs to focus on developing economic policies for an economy like the one in the third case, when an economy is poor in capital and has low rates of employment. These economic policies are targeted to help this economy to move from the lower left corner in figure 2. Developing such economic policies is the next step of this research.

The model of the economy in this paper assumes perfect labor and capital markets, and it assumes that no market for the harvested good exists. It might be different from a poor economy that does not really have perfect labor and capital markets and often has illegal markets for a harvested good. However, it has useful insights and policy implication for a more 'realistic' poor economy where the natural resources are an important part of household consumption. It suggests that when a regulator designs economic policies to improve such an economy that is trapped being poor, instead of traditionally focusing only on the resource regulation perhaps more effort should be put into improving the labor and capital markets. The policies that improve the labor market and provide the options for labor allocation other than harvesting divert the labor from harvesting into the wage earning alternatives. The important part of it is that economic incentives, instead of pure regulation, are at the core of this change in labor allocation.

4 Next steps

This research expands an economic growth model to include an open access natural resource. This allows for analyzing the dynamics of the households' consumption and allocation of labor between harvest of the resource and labor wages in a general equilibrium framework where households' decisions and equilibrium wages are endogenous. By thus expanding the model this research also develops a theoretical framework necessary to analyze a low-income economy because in such economy harvest of a natural resource is often an important part

of the households' consumption and income. This framework can also be used empirically to advise countries on the economic policies pertaining to economic development, establishment of well-functioning markets, and efficient natural resource extraction and protection policies. The contribution is not only to the science of economics, but also in applying it to maintain environment and improving wellbeing.

This paper derives the economic model, defines and characterizes an equilibrium. The analysis of steady state and approach dynamics shows that if an economy starts with high capital stock and high employment then it can converge to a steady state without depleting its resource stock even with no resource regulation. However, if an economy starts with low capital stock and low employment, then it can deplete its resource stock and converge to having an even lower capital stock and employment.

This suggests the next step of this research, mainly solving a regulator's or social planner's problem with the goal of identifying the set of economic policies that will help an economy to move away from decreasing labor employment and decreasing resource and capital stocks. That is the question that the next paper will address. As discussed in the previous section, these policies are not purely resource regulation policies, but also the policies targeted to improve capital and labor markets that provide better alternatives for a wage income.

References

Barrett, B. and P. Arcese. (1998). Wildlife harvest in integrated conservation and development projects: Linking harvest to household demand, agricultural production, and environmental shocks in the Serengeti. *Land Economics*. 74 (4): 449-65.

Brock, W. and A. Xepapadeas. (2002). Optimal ecosystem management when species compete for limiting resources. *Journal of Environmental Economics and Management*. 44, 189-220.

Cass, D. (1965). Optimum growth in an aggregative model of capital accumulation. *The Review of Economics Studies*. 32 (3) Jul.: 233-2450.

Conrad, J. and C. Clark. (1987). Natural Resource Economics. Cambridge University

Press.

Dasgupta, P. and K. Maler. (1995). Poverty, institutions, and the environmental resource-base. *Handbook of Development Economics*. 3: 2371-2462.

Koopmans, T. (1965). On the concept of optimal economic growth. In *The Econometric Approach to Development Planning*. North Holland.

Liobooki, M, H. Hofer, K. Campbell, and M. east. 92002). *Environmental Conservation*. 29 (3): 391-398.

Magill, M. and M. Quinzii. (1996). *Theory of Incomplete Markets*. The MIT Press.

Pascual, M. A. and R. Hilborn. (1995). Conservation of Harvested Populations in Fluctuating Environments: The Case of the Serengeti Wildebeest. *The Journal of Applied Ecology* 32 (3) Aug.: 468-480.

Ramsey, F. (1938). A mathematical theory of savings. *Economic Journal*. 387 (152) Dec.: 543-559.

Swinton, S. and G. Escobar. (2003). Poverty and Environment in Latin America: Concepts, evidence and policy implications. *World Development*. 31: 1865-1872.

Reardon, T. and S. Vosti, (1995). Links between rural poverty and the environment in developing countries: Asset categories and investment poverty. *World Development*. 23 1495-1506.