DEFORESTATION MECHANISM: AN ECONOMIC ANALYSIS BASED ON THE FOKKER-PLANCK EQUATION

Dradjad Hari Wibowo

This paper describes how the Fokker-Planck equation and the simulation of stochastic trajectories can be used to explain capital accumulation and deforestation process. The exploitation of the boundary conditions associated with this equation becomes the main tools of the analysis. Use of the Fokker-Planck enables us to construct a deforestation model without optimizing a farmer's consumption behavior. The farmer's consumption behavior can be treated as an arbitrarily determined parameter, by setting a given subsistence level.

INTRODUCTION

Suppose that we wish to predict future values an economic variable, say a price process, based on a set of past and current data. Because of noise, the motion of the price process becomes irregular and unpredictable. Consequently, we never are able to predict w.p.1 the exact position of the process, even in a not so distant future. While econometric modeling can be of aid in this task, more often economist are unable to assign the probability density that the price process will fall within a region. The Fokker-Planck (FP) equation is very useful technique to determine such a probability density.

The FP equation is also a powerful tool for analysts who wish to formulate boundary conditions for given stochastic process. To illustrate this, consider an Itô diffusion X_t taking values in *R* or R^n. Suppose that we wish to impose a boundary condition on X_t by restricting the sample space Ω to an interval [$x_{\min}$, $x_{\max}$]. If the drift away from the boundaries is sufficiently large, then the boundaries are "repelling" in the sense that the process X_t will be "repelled" every time the values of X_t almost reach the boundaries. Thus, the boundaries are inaccessible because the trajectory of X_t never reach them in this case it is imposible to impose boundary conditions on X_t. But if say, both the drift and diffusion terms of X_t vanish at a given boundary, then the boundary is "attracting" or "absorbing". Consequently, once the process X_t hits the boundary, it will stay there unless the drift and/or the diffusion parameters change. It also means that a process that starts at the boundary will never reach the interior.

Naturally, the question is then raised as to how SDEs and the FP equation can be used to explain the deforestation mechanism. This can be described as follows. Because a farmer's capacity to clear a forest depends on his or her agricultural and/or non-agricultural income process, the first step needed is to determine an SDE for this income process. Using this SDE, one can then employ the FP equation to show that without capital accumulation, the income process tends to stay in a absorbing boundary below given "target boundary", beyond which the farmer would be financially capable of clearing a forest. In this case, this "target boundary" represents the minimum cash capital required to a clear a forest and establish a *ladang*, as well as to support the farmer's family during the idle period between forest clearing and secondary crop harvests. Because capital accumulation is basically a different income process, one may simulate the drift and/or the diffusion parameters to construct an income process with or without capital accumulation. For this purpose, the Euler-Maruyama scheme can be used to approximate the income process. Thus, for the case of *anak ladangs,* for example, their deforestation behavior can be modeled by determining an SDE and a FP equation which show that their income process will not reach the "target boundary" before a cash surplus is obtained from cinnamon harvest.

Before proceeding further with the modeling, fundamental concepts of the FP equation will be described briefly in the next section[1]. Readers wishing to know further details about the FP equation are referred to *inter alia* Gardiner (1983), Honerkamp (1994), Ottinger (1996) and Risken (1989).

THE FOKKER-PLANCK EQUATION

Consider an SDE

$$dX_t = A(t, X_t)dt + \sigma(t, X_t)dB_t \tag{1}$$

where the drift $A(t,x)$ is interpreted in the Itô sense, $X_t \in R^n$, and B_t is an *m*-dimensional Brownian motion. The FP equation for this SDE is

$$\begin{aligned}\frac{\partial p(t,x)}{\partial_t} &= \sum_i \frac{\partial}{\partial x_i}\left(-A_i(t,x) + \frac{1}{2}\sum_k \frac{\partial}{\partial x_k} D_{i,k}(t,x)\right) p(t,x) \\ &= -\sum_i \frac{\partial}{\partial x_i} S_i(t,x) \end{aligned} \tag{2}$$

where $p(t,x)$ is a probability density, $S_i(t,x)$ a probability current, and $D = \sigma\sigma^T$.

From the equation (2), one can write the probability current $S_i(t,x)$ as

$$S_i(t,x) = (A_i(t,x) - \frac{1}{2}\sum_k \frac{\partial}{\partial x_k} D_{ik}(t,x))\, p(t,x) \tag{3}$$

In general, a closed form (time dependent) solution for the FP equation can only be found in a few cases. For example, in the case where the SDE (1) is linear with additive

[1] In probability theory, the PF equation is also known as the Kolmogorov's forward equation. Because this equation has found a wide range of applications in natural science, e.g. in polymer kinetic theory, solid-state physics, and theoretical biology, it is also known under a number of a different names such as the diffusion, the Klein-Kramers or the Smoluchowski equation.

noise, that is, when the drift term $A(t,x)$ is at most a polynomial of first degree in x and the diffusion term D is dependent of x. For SDEs with multiplicative noise, however, it is generally very difficult to find a closed form solution of the FP equation (see Gardiner, 1983, and Honerkamp, 1994, for further discussions).

One alternative method to find these closed form solutions is to first solve the SDE exactly and compute its mean and variance. These mean and variance are then used as a basis to solve the FP equation (2).

To illustrate this method, consider the Langevin version of equation: $dC_t = (-u_1 C_t + u_2)dt + vdB_t$, generalized in the following multi-dimensional case:

$$dX_i(t) = -\sum_{j=1}^{n} A_{ij}(t)X_j(t)dt + \sum_{j=1}^{n} \sigma_{ij}(t)dB_j(t); \quad \mathbf{X}(0) = \mathbf{x}_{0,} \tag{4}$$

where $X_i(t) \in \Re^n, A^t \in \Re^{n\times n}, \sigma(t) \in \Re^{n\times n}$, and *B(t)* is an *n*-dimensional Brownian motion.

The mean value of $X_i(t)$ is then given by

$$E(X_i(t)) = \sum_{j=1}^{n} \Phi_{ij}(t)(x_0)_j, \tag{5}$$

where

$$\Phi(t) = \left(\exp\left(-\int_0^t \mathbf{A}(s)\right)ds\right). \tag{6}$$

The readers can easily see that $\Phi(t)$ is in fact the fundamental solution of linear SDE with additive noise, as shown by equation $\Phi t, t_0 = \exp\int_0^t u_1(s)ds = e^{u_1(t-t_0)}$ for the 1-dimensional case.

Meanwhile, the general form of the variance of $X_i(t)$ is

$$\mathbf{\Lambda}(t) = \mathbf{\Phi}(t)(0)\mathbf{\Phi}^T(t) + \int_0^t \mathbf{\Phi}(t)\Phi^{-1}(s)\mathbf{D}(s)(\Phi^T)^{-1}(s)\mathbf{\Phi}^T(t)ds, \tag{7}$$

where $D(t) = \sigma(t)\sigma^T(t)$. Because X(0) = $\mathbf{x}_0$ then $\mathbf{\Lambda}(0) = 0$.

Proof: See Honerkamp (1994) pp. 256-261 for a proof.

The explicit solution of the equation (2) is then

$$p(t,x) = (2\pi)^{-n/2}\{\det(\Lambda(t))\}^{-1/2} \times \exp\left[-\frac{1}{2}(x - E(X(t))^T \times (\Lambda^{-1}(t))(x - E(X(t)))\right], \tag{8}$$

where *n* is the rank of the $\Lambda(t)$ matrix.

Now, consider the case where both **A** and **D** are time-homogeneous. In other words, the SDE (1) becomes an Itô diffusion. Provided that $E(X) \to 0$ as $t \to \infty$, one obtains the following stationary solution

$$p_{stat}(t,x) = (2\pi)^{-n/2}\{\det(\Lambda(\infty))\}^{-1/2} \times \exp\left(-\frac{1}{2}x^T(\Lambda^{-1}(\infty))x\right), \tag{9}$$

where

$$\mathbf{A}\boldsymbol{\Lambda}(\infty) + \boldsymbol{\Lambda}(\infty)\mathbf{A}^T = \mathbf{D}. \tag{10}$$

Example 1 (The AR(1) Consumption Process) *Suppose that the AR(1) consumption process of equation* $dC_t = (-u_1C_t + u_2)dt + vdB_t$ *can be expressed in the following Langevin equation:*

$$dC_l = -uC_l dt + vdB_l; \quad C(0) = c_0. \tag{11}$$

The mean value of C_l *is then* $E(C_l) = c_0e^{-ut}$*, whereas the variance is*

$$\Lambda(t) = e^{-2ut}\int_0^t e^{2us}v^2 ds = \frac{v^2}{2u}(1 - e^{-2ut}). \tag{12}$$

As the explicit solution of the FP equation for the Langevin equation (11). From this solution, we can compute the probability density of the consumption process C_t *taking a value of, say, c' at time t'. Meanwhile, the stationary solution for this FP equation is given by*

$$p_{stat}(c) = \left(\frac{2u}{2\pi v^2}\right)^{1/2}\exp\left(-\frac{uc^2}{v^2}\right), \tag{13}$$

as $e^{-t} \to 0$*. Note that in this case* $\Lambda_{stat} = v^2/2u$*.*

In most cases, however, it is very difficult to find the exact solution of an SDE. As a result, the above method of solving the FP equation cannot be applied. Nonetheless, one can still find a closed form stationary solution of the FP equation, without necessarily having to find the exact solution of the SDE beforehand.

For a stationary solution $p_{stat}(x),$ the probability current $S_{stat}(x)$ vanishes in the entire sample space. Thus $S_{stat}(x) \equiv 0$ for all x. Equation (3) then becomes

$$A_i(x)\, p_{stat}(x) = \frac{1}{2}\sum_k \frac{\partial}{\partial x_k} D_{ik}(x)\, p_{stat}(x). \tag{14}$$

To gain intuition, consider first the one-dimensional version of equation (14). Multipliying the left-hand side by *D(x) / D(y)* and rearranging gives

$$\begin{aligned}\frac{A(x)}{D(x)} &= \frac{1}{2}\frac{\frac{d}{dx}D(x)\,p_{stat}(x)}{D(x)\,p_{stat}(x)} \\ &= \frac{1}{2}\frac{d}{dx}\ln D(x)\,p_{stat}(x).\end{aligned} \tag{15}$$

Integrating both sides gives

$$\int_x \frac{A(\bar{x})}{D(\bar{x})}\,d\bar{x} = \frac{1}{2}\ln D(x)\,p_{stat}(x) + \ln N_0. \tag{16}$$

Making use of Honerkamp's (1994) definition of the potential function[2] $\Psi(x),$ take the exponent of both sides and rearrange to have

$$\begin{aligned}p_{stat}(x) &= \frac{N}{D(x)}\exp\left(\int_x \frac{2A(\bar{x})}{D(\bar{x})}\,d\bar{x}\right) \\ &= N\exp(-2\Psi(x)),\end{aligned} \tag{17}$$

where N is a normalization factor. Taking logarithm of the two right-hand side term of equation (17) and rearranging gives the potential

$$\Psi(x) = \frac{1}{2}\ln D(x) - \int_x \frac{A(\bar{x})}{D(\bar{x})}d\bar{x}. \tag{18}$$

For the Stratonovich interpretation of equation (1), the drift term A(x) becomes

$$\begin{aligned}A(x) + \frac{1}{2}\left(\frac{d}{dx}D^{\frac{1}{2}}(x)\right)D^{\frac{1}{2}}(x) &= A(x) + \frac{1}{2}D(x)\frac{\frac{d}{dx}D^{\frac{1}{2}}(x)}{D^{\frac{1}{2}}(x)} \\ &= A(x) + \frac{1}{2}D(x)\frac{d}{dx}\ln D^{\frac{1}{2}}(x),\end{aligned} \tag{19}$$

where $D^{\frac{1}{2}}(x) = \sigma(x).$ Replacing the Itô drift term in equations (14) to (18) by the drift term (19) gives the following Stratonovich interpretation of the stationary solution:

[2] See equation (9.4.6) of Honerkamp (1994)

$$p_{stat}(x) = \frac{N}{D^{\frac{1}{2}}(x)} \exp\left(\int_x \frac{2A(\bar{x})}{D(\bar{x})} d\bar{x} \right)$$
$$= N \exp(-2\Psi(x)). \tag{20}$$

The Stratonovich potential is given by

$$\Psi^s(x) = \frac{1}{4} \ln D(x) - \int_x \frac{A(\bar{x})}{D(\bar{x})} d\bar{x}. \tag{21}$$

Combining equations (18) and (21), one obtains

$$\Psi(x) = \frac{m}{4} \ln D(x) - \int_x \frac{A(\bar{x})}{D(\bar{x})} d\bar{x}, \tag{22}$$

where m = 2 for the Itô interpretaion and m = 1 for its Stratonovich counterpart. The extrema of $\Psi(x)$ are then given by

$$A(x) - \frac{m}{4} \frac{d}{dx} D(x) = 0,\ D(x) \neq 0, \tag{23}$$

After setting $d/dx\Psi(x) = 0$.

For the multi-dimensional case, the probability current (equation 3) does not generally vanish in the stationary state (Risken, 1989). Consequently, the stationary solution for a multi-dimensional case is not a straigtforward extention of its one-dimensional counterpart. Only under a certain condition of the potential function does the probability current vanish. Honerkamp (1994) and Risken (1989) show that this condition is

$$\frac{\partial Z_i}{\partial x_k} = \frac{\partial Z_k}{\partial x_i}, \tag{24}$$

where

$$Z_k(x) \equiv \frac{\partial}{\partial x_k} \ln(p(x))$$
$$\sum_i (\mathbf{D}^{-1})_{ki}(x) \left[2A_i(x) - \sum_j \frac{\partial}{\partial x_j} D_{ij}(x) \right], \tag{25}$$

provided that the matrix **D**(x) has an inverse everwhere. Equation (24) implies that Z_k is the gradient of the potential Ψ**,** which is given by

$$\Psi(x) = -\frac{1}{2} \int_x Z_i(z) dz_i. \tag{26}$$

One then obtains the stationary density

$$p_{stat} = N \exp(-2\Psi(x)). \tag{27}$$

Now consider a region $\mathbf{V} = [\mathbf{x}_{\min}, \mathbf{x}_{\max}] \in \Re^n$. Using the potential function $\Psi(\mathbf{x})$, the boundary conditions for the FP equation can be stated as follows (Risken, 1989):

- If goes to an (infinite) high positive value at $\mathbf{x} = \mathbf{x}_{\max}$, the process is never allowed to enter the region $\mathbf{x} > \mathbf{x}_{\max}$. It means, there is no current accross $\partial\mathbf{V}$ at $\mathbf{x} = \mathbf{x}_{\max}$ and the probability current **S**(x) vanishes at this point. Consequently, the upper bound $\mathbf{x} = \mathbf{x}_{\max}$ acts as repelling boundary. A similiar rule applies for $\mathbf{x} = \mathbf{x}_{\min}$.
- If $\Psi(\mathbf{x})$ falls to an (infinite) high negative value at $\mathbf{x} = \mathbf{x}_{\max}$, then $e^{\Psi} p$ vanishes at this point. In this case we have an absorbing boundary at $\mathbf{x} = \mathbf{x}_{\max}$, and again, a similar rule applies for $\mathbf{x} = \mathbf{x}_{\min}$.

From these boundary conditions, one has four boundary possibilities for the region V, that is,

- Both $\mathbf{x}_{\min}$ and $\mathbf{x}_{\max}$ are repelling boundaries,
- Both $\mathbf{x}_{\min}$ and $\mathbf{x}_{\max}$ are absorbing boundaries,
- $\mathbf{x}_{\min}$ and $\mathbf{x}_{\max}$ are repelling and absorbing boundaries, respectively, and vice versa.

THE FOKKER-PLANCK EQUATION FOR DEFORESTATION

The Model

In this subsection, the FP equation for farmer's deforestation behavior is modeled. The representative farmer is treated as a producing and consuming agent simultaneously. To begin, let

$$X_t = X_{1t} + X_{2t} \tag{28}$$

be the farmer's (discrete) cash on hand, where X_{1t} represents financial assets consisting mostly of cash saving[3] and X_{2t} represents stochastic income form farm

[3] A small number of farmers may keep a rural bank account and/or a set of jewelry as their financial assets. However, such a case is not a common one in the the study area.

production and/or working as wage laborer. Once realized, X_t is allocated into consumption $C_t = u_{1t} X_t$, income-generating expenses $Q_t = u_{2t} X_t$, and forest clearing expenses $L_t = u_{3t} X_t$. Note here that Q_t does not include land acquisition expenses, but it includes expenditure such as work related traveling expenses and purchases of farm inputs and equipment. Also note that $L_t = 0$ if $X_t < \overline{X} = B + \overline{C} + \overline{Q}$, where B is minimum cash capital required to clear a forest and establish a *ladang,* $\overline{C} \le C_t$ is consumption at the subsistence level, and $\overline{Q} \le Q_t$ the minimum level of income-generating expenses. For simplicity, the components of the "target boundary" $\tilde{X}_t$ are assumed to be time-independent and given. Finally, it is assumed that stockpiles of grain and non-edible farms produces are considered as imputed X_{2t} valued at the farm-gate price. So are portions of farm outputs consumed by the farmer's own family.

Let $\overline{\theta}_t = \sum_{i=1}^{3} u_{it}$. The income residual (or saving) $\tilde{X}_t$ is then given by $\tilde{X}_t = (1 - \overline{Q}_t) X_t$ where $\overline{\theta}_t \in (0,1]$. Because the rural financial sector in the study area is relatively under-developed (compared to its urban counterpart), farmers usually keep their income residual at home as a cash saving. Thus, the saving attracts no interest revenues. For analytical convenience, however, a non-stochastic return r ≥ 0 on the financial assets is assumed.

Following Deaton (1992), the financial asset X_{1t} evolves according to the discrete process

$$\begin{aligned} X_{1(t+1)} &= (1+r)(1-\overline{\theta}_t)X_t \\ &= X_{1t} + [r(1-\overline{\theta}_t) - \overline{\theta}]X_{1t} + (1+r)(1-\overline{\theta}_t)X_{2t}, \end{aligned} \tag{29}$$

Rearranging and letting $\Delta t = 1$, one obtains:

$$\Delta X_{it} = \left[(1 + r(1-\overline{\theta}_t) - 1\right] X_{it}\Delta t + (1+r)(1-\overline{\theta}_t)X_{2t}\Delta t. \tag{30}$$

From Euler-Maruyama scheme we know that equation (30) corresponds to a continuous function

$$dX_{1t} = [(1+r)(1-\overline{\theta}_t) - 1]X_{1t}dt + (1+r)(1-\overline{\theta}_t)X_{2t}d_t + f(t, X_{1t})dB_{1t}, \tag{31}$$

where $f(t, X_{1t})$ is a function and dB_{1t} is one-dimensional Wiener process representating stochastic *r.* Because *r* is non-stochastic, then $f(t, X_{1t})dB_{1t} = 0$.

Assuming time-homogeneous u_i, the income process X_{2t} can be interpreted as an Itô diffusion. One reasonable approach to constructing the process X_{2t} is by assuming that it depends on u_2[4] and the stochasticity of farm income and rural employment opportunities[5]. Because the majority of rural employment opportunities come from the agricultural sector, its stochasticity is assumed to be represented b the governing the farm income process. Thus, we have a one-dimesional Wiener process B_t representating the farmer's stochastic income.

Now consider the logistic model

$$dX_{2t} = u_2(X_{it} + X_{2t})(1 - \frac{X_{2t}}{K})dt + \alpha X_{2t}(1 - \frac{X_{2t}}{K})dB_t, \qquad (32)$$

as a parameterization of the income process X_{2t}, where K and α are the carrying capacity and the diffusion parameter, respectively. One advantages of the logistic model is that it does not allow the income process to grow indefinitely, which would be the case had a linear model been adopted. Instead, the process is limited by carrying capacity K, which can be associated with natural constraints such as limited soil nutrient supply and the fact that different crops and crop varieties have different income-generating capacities. It is this carrying capacity that will be exploited further in the later part of this modeling.

Because $dX_t = dX_{1t} + dX_{2t}$, where X_{1t} and X_{2t} can be written as $X_{1t} = (1+r)(1-\bar{\theta}_t)X_t$ and $X_{2t} = X_t - X_{1t} = [1-(1+r)(1-\bar{\theta}_t)]X_t$, respectively, we then have

$$dX_t = (aX_t - bX_t^2)dt + (gX_t - hX_t^2)dB_t, \qquad (33)$$

where $a = u_2 \in (0,1)$, $b = u_2\theta/K$, $g = \alpha\theta$, $h = \alpha\theta^2/K$ and $\theta = 1-(1+r)(1-\bar{\theta})$. If $b = 1$ and $h = 0$, equation (7) reduces to the (stochastic) multiplicative Verhulst model, whose exact solution is given by[6]

[4] This assumption represent the production side of the model.
[5] It may result from uncertain weather and output prices.
[6] See Kloeden and Platen (1992) pp. 124-125.

$$X_t = \frac{X_0 \exp\left(\left(a - \frac{1}{2}g^2\right)t + gB_t\right)}{1 + X_0 \int_0^t \exp\left(\left(a - \frac{1}{2}g^2\right)s + gB_s\right)ds}. \tag{34}$$

Now rewrite equation (33) as

$$dX_t = A(X_t)dt + \sigma(X_t)dB_t, \tag{35}$$

where $A(X_t) = aX_t - bX_t^2$ and $\sigma(X_t) = gX_t - hX_t^2$. Applying the FP equation (2) and recalling that differential operators act on *A(x)*, $\sigma^2(x)$ and *p(t,x)* we have

$$p_t = (\sigma_x^2 + \sigma\sigma_{xx} - A_x)p + (2\sigma\sigma_x - A)p_x + \frac{1}{2}\sigma^2 p_{xx}, \tag{36}$$

where the subscripts denote partial differential operators w.r.t. the subscripted argument, with $A = ax - bx^2$, $A_x = a - 2bx$, $\sigma = gx - hx^2$, $\sigma_x = g\text{-}2hx$, $\sigma_{xx} = 2h$ and $\sigma^2 = (gx - hx^2)^2$. Thus, the FP equation (36) takes the form of second-order linear homogeneous partial differential equation (PDE)[7] which is uniformly parabolic on *x*.

In general, it is difficult to find an explicit solution for thee FP equation (36). Because this modeling aims at explaining deforestation behavior, not at finding exact solutions of the SDE (33) and he FP equation (36) as such, this route of solving for *p(t,x)* is not adopted for time-efficiency reason. Instead, the stationary solutions of the problem will be determined.

Taking the Itô interpretation of equation (22), one obtains the potential

$$\Psi(x) = \frac{1}{2}\ln(gx - hx^2)^2 - \int_x \frac{(a\bar{x} - b\bar{x}^2)}{(g\bar{x} - h\bar{x}^2)^2} d\bar{x}. \tag{37}$$

Using the partial fractions technique to solve the integral equation (37) gives

$$\int_x \frac{(a\bar{x} - b\bar{x}^2)}{(g\bar{x} - h\bar{x}^2)^2} d\bar{x} = \frac{ah - bg}{gh}(g - hx)^{-1} - \frac{a}{g^2}\ln(g - hx) + \frac{a}{g^2}\ln x + N_0. \tag{38}$$

Thus for $h \neq 0$ and $x \neq g/h$ we have

$$\Psi(x) = (1 - \frac{a}{g^2})\ln x + (1 + \frac{a}{g^2})\ln(g - hx) - \frac{ah - bg}{gh(g - hx)} + N_0 \tag{39}$$

as the potential function for the generalized Velhust model of equation (33). However, because in this study the parameters *a, b, g* and *h* are specified in such a way that

[7] See, for example, Stephenson (1996) for detailed description of PDEs

$(ah - bg)/gh = 0$, the last term equation (39) can be eliminated. Hence, the potential function for this study's FP modeling is given by

$$\Psi(x) = (1 - \frac{a}{g^2}) \ln x + (1 + \frac{a}{g^2}) \ln(g - hx) + N_0,$$

which can be simplified into

$$\Psi(x) = (1 - \frac{a}{g^2}) \ln x + (1 + \frac{a}{g^2})(\ln g + \ln(1 - \frac{b}{a}x)) + N_0 \qquad (40)$$

because $h = bg/a$.

The logarithmic terms of this equation indicate that at $x = 0$ and $x = a/b = K/\theta$ the potential function is asymptotic. They also make $\psi(x)$ not applicable for the regions of $x < 0$ and $x > a/b = K/\theta$. Because of these restrictions, especially the former one, one may think that the Verhulst model used here fails to accommodate the case where at some points of time the economic agent is a net borrower. Such an interpretation is however incorrect. The model can still accommodate borrowing, for example, by adding a net borrowing variable into equation (28) or (29)[8]. From here, we can proceed with the technical procedures described above.

With equation (40) as the potential function, the stationary density function is given by

$$p_{stat}(x) = N x^{z_1} (g(1 - \frac{b}{a}x))^{z_2} \qquad (41)$$

where N is normalized into unity, $z_1 = 2(a/g^2 - 1)$ and $z_2 = -2(a/g^2 + 1)$.

We can easily see that z_2 always takes a negative value, regardless of the ratio between a and g^2. However, such a consistency is not applicable for z_1, because z_1 has a positive value if $a > g^2$ and a negative value if $a < g^2$. A zero valued z_1 is obtained if $a = g^2$. Consequently, depending on whether the ratio between a and g^2 is greater or less than unity, different functional forms for $p_{stat}(x)$ will be obtained. It means, the ratio determines the transition of $p_{stat}(x)$, by which the condition $a = g^2$ separates the two regimes of z_1 term.

[8] A similar strategy has been adopted by Hubbart *et. al.* (1995) in their study of precautionary saving and social insurance.

This transition of the density function has a significant impact on the derivation of the boundary conditions. To see this, let us first determine the extrema of the stationary solution. By applying equation (23), we have

$$(ax - bx^2) - (gx - hx^2)(g - 2hx) = 0 \qquad (42)$$

Because *h=bg/a,* we can simplify equation (7.42) into

$$x(1 - \frac{b}{a}x)(a - g^2 + \frac{2g^2 b}{a}x) = 0 \qquad (43)$$

and obtain the following extrema

$$\dot{x}_1 = 0; \quad \dot{x}_2 = \frac{a}{2b}(1 - \frac{a}{g^2}) = \frac{K}{2\theta}(1 - a\alpha^2\theta^2); \quad \dot{x}_3 = \frac{a}{b} = \frac{K}{\theta} \qquad (44)$$

where at $\dot{x}_1$ and $\dot{x}_3$ the potential function is asymptotic.

Now take for example the case of $\dot{x}_1 \downarrow 0$ is always a minimum, making it a candidate for an absorbing boundary. On the contrary, if $a > g^2$, the extremum $\dot{x}_1 \downarrow 0$ is a maximum. Consequently, this extremum represents a possible repelling boundary.

An evaluation of the value of $\psi(x)$ around $\dot{x}_1 \downarrow 0$, however, shows that the boundary conditions at this extremum also depend on the magnitude of the ratio a/g^2, not only on whether a is greater or less than g^2. As can be seen from Table 1, for both the $a > g^2$ and $a < g^2$ cases, the potential function goes to a larger positive or negative value, respectively, if the difference between a and g^2 is larger. This means, the greater is the deviation between a and g^2, the bigger is the likelihood that $\dot{x}_1 \downarrow 0$ becomes a repelling or absorbing boundary.

To have a better idea of how the transition of the density function affects the boundary conditions, some plots of the potential function are represented in Figure 1. Here the values of $\alpha = 0.5$ and $\theta = 0.95$, resulting in $g^2 = 0.2256$. Assuming that $K = 5$, the $a > g^2$ and $a < g^2$ cases are represented by $a = 0.3$ and $a = 0.2$, respectively. Note here that the ratio of a/g^2 is chosen in such a way that the plots of the potential function for both the $a > g^2$ and $a < g^2$ cases can be put together in one figure. The plot for the $a = g^2$ case is also presented in Figure 1.

We can see from Figure 1 that the transition is particularly important for the boundary condition at $\dot{x}_1 \downarrow 0$. With the aid of Table 1, it can be inferred from this figure that if g^2 is sufficiently larger than a, the potential function $\psi(x)$ will slowly go to a large negative value. Thus, as g^2 increases relative to *a,* the extremum $\dot{x}_1 \downarrow 0$ is increasingly likely to become an absorbing boundary. On the contrary for the $a > g^2$ case, the potential goes more rapidly to a large positive value at this extremum. It means, this extramum becomes a repelling boundary.

Figure 1 also shows that potential function approaches negative infinity exponentially rapidly at $\dot{x}_3 \uparrow (a/b)$, regarless of the value of *a* and g^2. This means, the extremum $\dot{x} \uparrow (a/b)$ is "naturally" absorbing boundary, no matter whether *a* is larger or less than g^2. Finally, Figure 1 shows that extremum $\dot{x}_2$ is a local minimum. Consequently, this extremum imposes no boundary conditions for the process X_t.

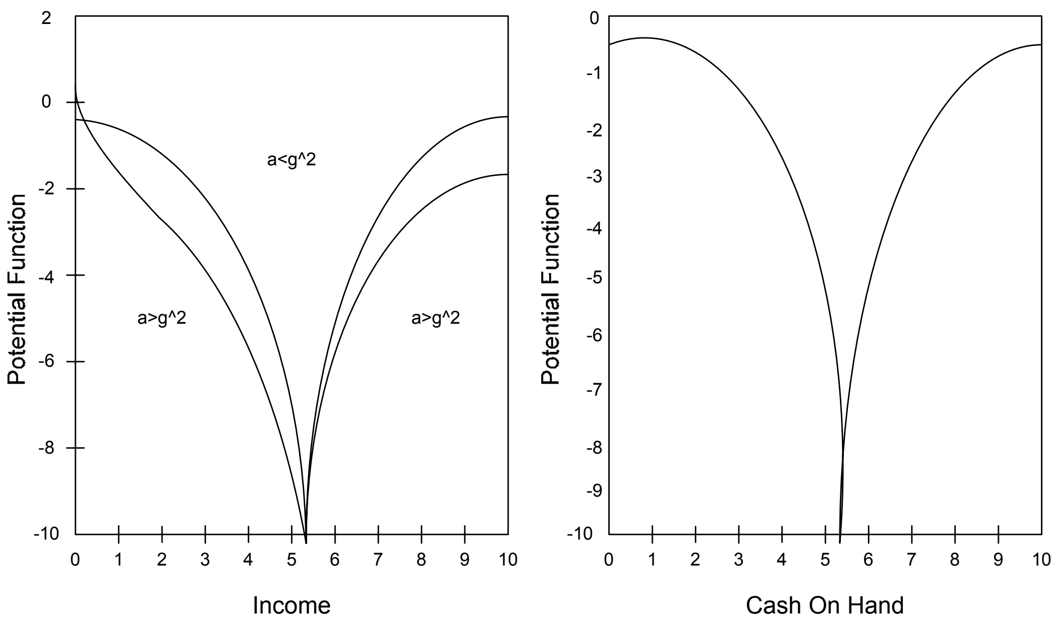

Figure 1. Some Plots of the Potential Function

Having established the boundary conditions for X_t, we can now proceed with numerical simulations of the process trajectories and see under what conditions X_t exceeds the target boundary $\overline{X}$. In these simulations, the Euler Maruyama scheme is employed and the data reported in Wibowo, D.H., Tisdell, C.A. and Byron, R.N. (1997) are used. For brevity reasons, however, only simulations that use the upper Kerinci data are presented. The same simulations can be easily repeated for lower Kerinci region.

Tabel 1. Evaluating of the Values of the Potential Function at the Lower Boundary

a	**saving**	***alpha***	***g^2***	**Potential**
0.6	0.03	0.20	0.04	1.E+04
0.6	0.03	0.01	0.00	4.E+06
0.6	0.05	0.20	0.04	1.E+04
0.6	0.05	0.01	0.00	5.E+06
0.7	0.03	0.20	2.11	1.E+04
0.7	0.03	0.01	23.45	5.E+06
0.7	0.05	0.20	2.02	1.E+04
0.7	0.05	0.01	22.44	5.E+06
0.6	0.03	1.50	2.11	-5.E+02
0.6	0.03	5.00	23.45	-7.E+02
0.6	0.05	1.50	2.02	-5.E+02
0.6	0.05	5.00	22.44	-7.E+02
0.7	0.03	1.50	2.11	-5.E+02
0.7	0.03	5.00	23.45	-7.E+02
0.7	0.05	1.50	2.02	-5.E+02
0.7	0.05	5.00	22.44	-7.E+02

Notes :

x = 1.E-305
r = 0.05
K = 5

Numerical Simulations

Now consider the case of an *anak ladang* in the upper Kerinci region. Assuming a time unit of “a month”[9], at the current average size of land operated we have a monthly output value of around, roughly, Rp. 200,075.00[10]. This value is used as the basis for normalizing the other monetary measurements, such as the “target boundary” $\overline{X}$ and carrying capacity *K.* Using table 1 and 2 of appendix, one obtain a rough estimate of u_1 = 0.40 and $u_2 = a = 0.57$, resulting in $(1-\overline{\theta}) = 0.03$ and $\theta = 0.97$. Here an $r = 0.05$ has been assumed in the calculation of θ[11].

[9] This time unit is chosen for convenience only. One may prefer to use other time units such as a week, a season or a year.
[10] See Table 1 of Appendix
[11] This assumption is made based on the level of interest rate paid by state-owned banks on rural saving accounts prior to the economic crisis.

Furthermore, if we take the amount of living allowance provided by landowners[12] as the subsistence level, we then have $\overline{C}$ = Rp. 53,500.00 before normalization. In the case it has been conservatively assumed that the farmer only needs to have a cash advance to support his or her family during the first month of the idle period, that is, the period between forest clearing and the first harvest of the annual crop. Because the minimum size of forest cleared by the respondents in a one round of clearing is 0.45 hectare, while the minimum capital required for forest clearing and *ladang* establishment is Rp. 750,000.00/hectare, we have B = 337,500.00. Assuming that the monetary value of $\overline{Q}$ is set at Rp. 111,130.00, that is, the minimum amount of cash capital needed to begin potato farming, the value of $\overline{X}$ is then = Rp. 502,180.00. After normalization, we have $\overline{X}$ = 2.51. Moreover, because the maximum of the potato yield data is 1.175 times the average figures reported in table 3 of appendix, whereas the highest level of farm-gate price for potato, under normal condition[13], was in the order of 1.15 times the average prices, K is then assumed to take the value of 1.175 x 1.15 = 1.35. This value represents the carrying capacity of the X_t process without capital accumulation via cinnamon plantation. Finally, the initial value X_0 is assumed to be 0.56, which is equal to $\overline{Q}$. Thus, the farmer is assumed to have enough cash capital to begin potato farming[14].

From the boundary conditions at $\dot{x}_3$, it is very straightforward to see that the process X_t never move beyond the boundary $\dot{x}_3$=1.39. It means, once the process reaches $\dot{x}_3$, if it ever reaches this extremum, the process will be absorbed in this boundary. In other words, because at K=1.35 the process X_t never come closer to the "target boundary" $\overline{X}$ = 2.51, hence the *anak ladang* in question never have the financial capacity to clear a forest.

This intuitive analysis, however, does not explain how X_t fluctuates and reaches the boundaries, especially the "target boundary". For this reason, Figure 2 to 4 are presented[15]. In Figure 2 the trajectories of X_t are shown to be fluctuating inside the

[12] This is the living allowance specified under the 1:2 sharecropping contract.
[13] That is, prior to the economic crisis
[14] Note that the issue of where this initial capital comes from it is not of concern here. Thus, the capital may originate from inside or outside the agricultural sector, either from the farmer's own resources and/or from the landowner's.
[15] Note that in these figures the numerics on the "time" axis does not necessarily represent the "time unit" used in the text, that is, a month. One may interpret each numerics as, say, a "year" or a "season", and

lower interior at the earlier stages of the process. However, because for the $a > g^2$ case the extremum $\dot{x}_1$ is a repelling boundary, the process X_t will not collapse into a zero value. Instead, the process can quickly gain momentum to move into the upper interior and stays at the absorbing boundary of $\dot{x}_3 \uparrow (K/\theta)$. A similar pattern is also observed for the $a = g^2$ case presented in Figure 3.

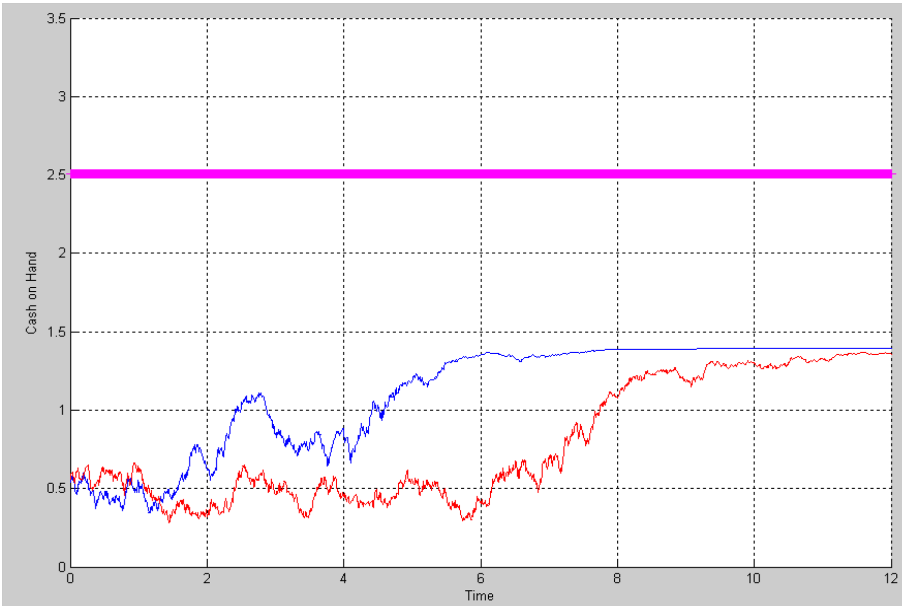

Figure 2. Some trajectories of X_t for the $a > g^2$ case without capital accumulation, where $\alpha = 0.75$

obtain the necessary intervals for the time used. For example, if the numerics is interpreted as a "year", then the "month" is represented by 1/12 of each interval (say, between 0 and 1) in the "time" axis.

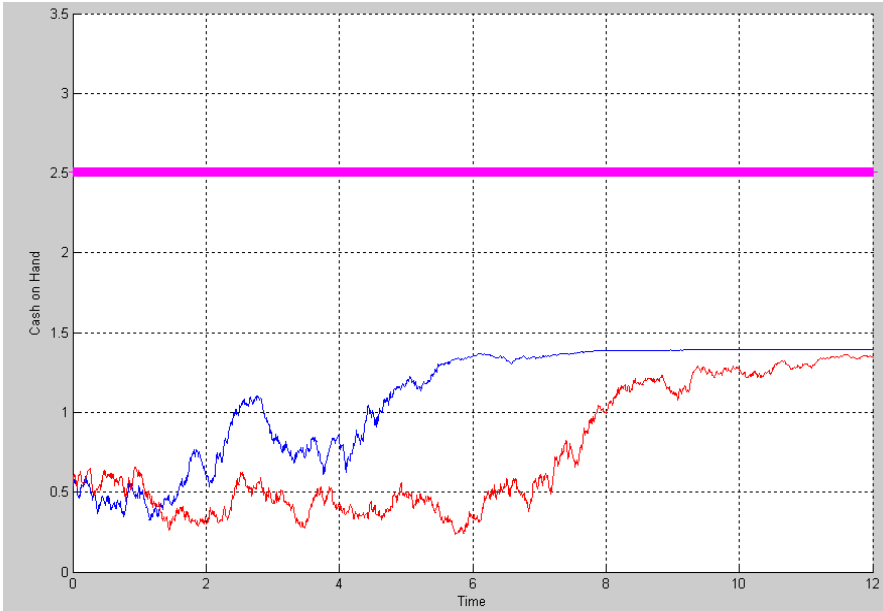

Figure 3. Some trajectories of X_t for the a = g^2 case without capital accumulation, where α = 0.78

For the $a < g^2$ case, provided that g^2 is not sufficiently larger than *a,* the process can still reach the upper absorbing boundary. Nonetheless, compared to the $a > g^2$ and $a = g^2$ cases, the process takes a relatively longer time at the lower interior, before gaining necessary strength to move up to the upper boundary. This pattern can be seen in figure 4. The level of uncertainty caused by g^2, which is due mostly to the high value of the diffusion parameter α, is the reason behind this pattern.

If, however, value of g^2 is sufficiently larger than that of *a,* the extremum $\dot{x}_1$ may then become a (lower) absorbing boundary. Consequently, the process X_t may collapse into a zero value unless the initial value is sufficiently large to prevent such a collapse. These cases are represented in Figure 5, where it is shown that if X_0 is set at some larger number, say X_0 = 0.9, then the process X_t may have the strength to eventually reach the upper boundary. Nonetheless, even at this larger X_0, there is still a chance that the process collapses to a zero value.

The next question is then of how the process can break the boundary $\dot{x}_3$=1.39 and moves to the "target boundary" $\overline{X}$ = 2.51. Because $\dot{x}_3$ is an absorbing boundary, changing the parameters *a,* α and θ will not carry X_t into regions above the boundary. Thus, it is only the carrying capacity *K* that is capable of doing so. In this case, a farmer might increase the value of *K* by, say, increasing the size of land operated and/or adopting a multicropping system. These ways of increasing *K* are in fact the ones adopted by farmers in the study area[16]. As discussed before, multicropping involving cinnamon and potato is the most popular farming system found in a *ladang.*

Also, *anak ladangs* usually operate another *ladang* once annual crops can no longer be planted on the previous *ladang* due to shading by cinnamon tress. As a result, the *anak ladangs* still obtain income from potato during this period[17]. While at the same time waiting for a "lump sum" to be received when cinnamon tress from the previous *ladang* are harvested. In other words, the process of capital accumulation (as represented by cinnamon plantation) provides additional income for the farmers, and thus, increases the value of *K.* Because the amount of the lump sum is 2.26 larger than the potato income, by conservatively ignoring additional income that may result from possible increases in cinnamon price, one has *K* = 2.26 x 1.35 = 3.05. This value of *K* represents the upper absorbing boundary.

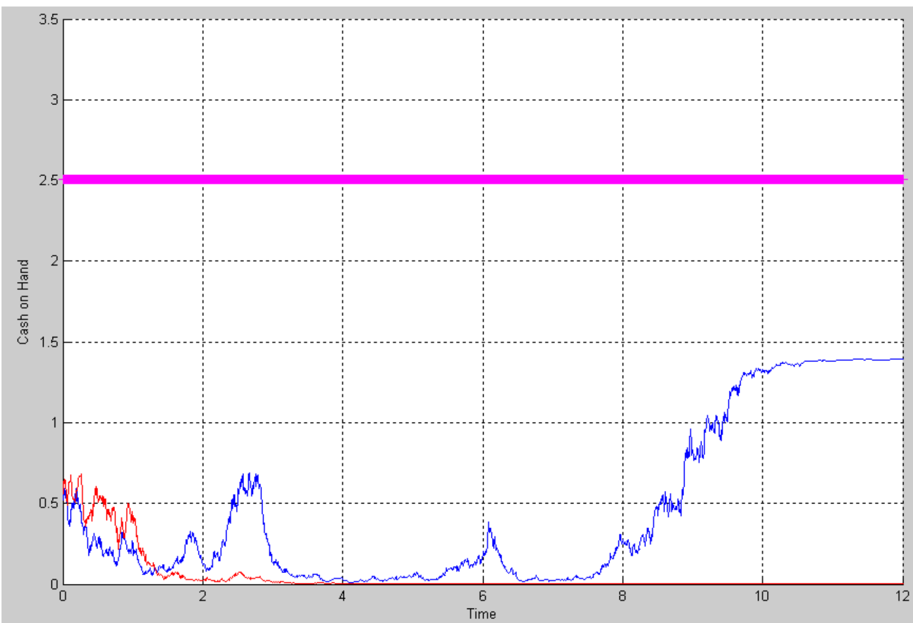

Figure 4. Some trajectories of X_t for the $a < g^2$ case without capital accumulation, where $\alpha = 1.5$

[16] Of course there are other means of doing so. For example, the farmer may adopt a more technologically intensive production system, switch into a more profitable crop(s). and/or improves his or her marketing and pricing strategies. But these alternatives are not commonly adopted in the study area.
[17] That is, from potato planted on the other *ladang*.

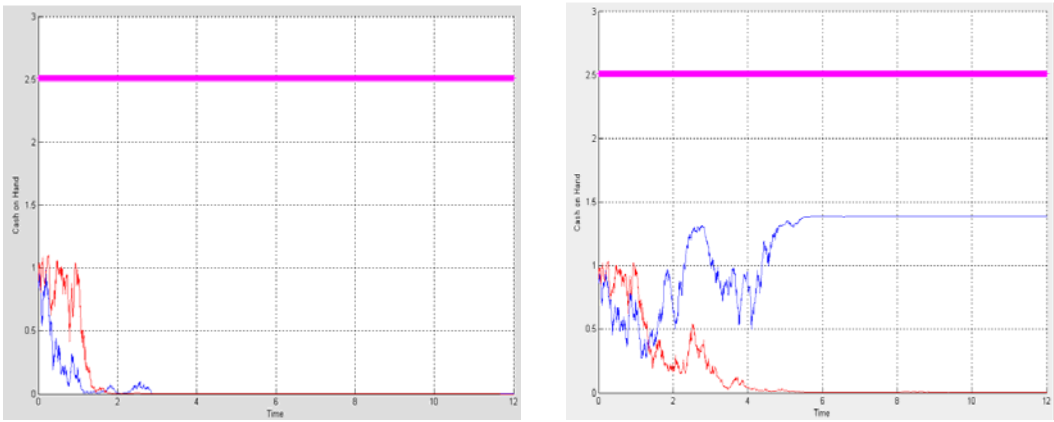

Figure 5. Some trajectories of X_t for the a < g^2 case without capital accumulation, where α = 2.5. The existence of two absorbing boundaries at x = 0 and x = K/θ causes some trajectories to collapse into zero value, while some others reach the upper absorbing boundary

The results of the simulation are presented in Table 2 and Figures 6 to 9. For the $a > g^2$ and $a = g^2$ cases (i.e. cases #1 and #2 in Table 2), it can be seen easily from Figure 6 that X_t will eventually pass the "target boundary" $\overline{X}$ = 2.51 and stays at the absorbing boundary $\dot{x}_3$=3.14. This is despite the fact that initial value X_0 and the saving parameter (1-$\overline{\theta}$) are set at a relatively low value. Thus, under these conditions the farmer is able to obtain enough cash capital to clear a forest, despite his or her low initial capital and saving level.

Now let us evaluate the more interesting case of $a < g^2$. Case #3 in Table 2 and Figure 7 is in fact the capital accumulation version of the case depicted in Figure 4. In the former, with a higher value of K, it is shown that with a lower value of K, the process X_t can gain enough strength to reach the upper absorbing boundary $\dot{x}_3$. Because the value of $\dot{x}_3$ in Figure 7 is 3.14, while in Figure 4 we have $\dot{x}_3$ = 1.39, this result indicates that increasing the value of K brings with it a higher risk for X_t to collapse into a zero value. This is because with it a lower K (and hence a lower $\dot{x}_3$), it is much easier for X_t to reach the upper absorbing boundary. With a higher K, however, the process fluctuates longer in the interior and may not have enough strength to reach $\dot{x}_3$. The uncertainty represented by g^2 can then force the process to fall into the lower absorbing boundary.

If, however, the farmer increases his or her saving level, the process X_t may have enough strength to reach both the target boundary of $\overline{X}$ = 2.51 and the upper absorbing boundary of $\dot{x}_3 = 3.14$. This result comes from the fact that given a constant r, increasing the saving parameter $(1-\overline{\theta})$ reduces the value of θ, which in turn lowers that of g^2. As it decreases, g^2 becomes not sufficiently large to induce X_t to collapse into the lower absorbing boundary. To give example of this result, case #4 is presented on the right-hand side of Figure 7, where the saving parameter $(1-\overline{\theta})$ has been set at a 10 percent level.

Nonetheless, with increased uncertainty, the results can be significantly different. This condition is represented by cases #5 to #8, where a higher diffusion parameter $\alpha = 2.5$ is assumed. As can be seen from Figures 8 and 9, the process X_t still collapses even though the initial value X_0 and/or the saving parameter $(1-\overline{\theta})$ are increased. In case #8, for example, having a relatively high $X_0 = 2.00$ and $(1-\overline{\theta}) = 0.10$ still fails to prevent the process from falling into a zero value. This result implies that higher initial value and/or saving level can only sufficiently large. Finally, Figure 8 also highlights the risk associated with increased K value, which can be seen by comparing case #5 in this figure with the results of Figure 5.

Table 2. Simulations of X_t

Cases	**Results**
1. $a > g^2$, $a = 0.57$, $g^2 = 0.53$, $(1-\overline{\theta}) = 0.03$, $\theta = 0.97$, $\alpha = 0.75$, $X_0 = 0.56$	$\overline{X}$ *reached*
2. $a = g^2$, $a = 0.57$, $g^2 = 0.57$, $(1-\overline{\theta}) = 0.03$, $\theta = 0.97$, $\alpha = 0.78$, $X_0 = 0.56$	$\overline{X}$ *reached*
3. $a < g^2$, $a = 0.57$, $g^2 = 2.12$, $(1-\overline{\theta}) = 0.03$, $\theta = 0.97$, $\alpha = 1.50$, $X_0 = 0.56$	X_t *collapses*
4. $a < g^2$, $a = 0.57$, $g^2 = 1.80$, $(1-\overline{\theta}) = 0.10$, $\theta = 0.895$, $\alpha = 1.50$, $X_0 = 0.56$	$\overline{X}$ *reached*
5. $a < g^2$, $a = 0.57$, $g^2 = 5.88$, $(1-\overline{\theta}) = 0.03$, $\theta = 0.97$, $\alpha = 2.50$, $X_0 = 0.90$	X_t *collapses*
6. $a < g^2$, $a = 0.57$, $g^2 = 5.00$, $(1-\overline{\theta}) = 0.10$, $\theta = 0.895$, $\alpha = 2.50$, $X_0 = 0.90$	X_t *collapses*
7. $a < g^2$, $a = 0.57$, $g^2 = 5.88$, $(1-\overline{\theta}) = 0.03$, $\theta = 0.97$, $\alpha = 2.50$, $X_0 = 2.00$	X_t *collapses*
8. $a < g^2$, $a = 0.57$, $g^2 = 5.00$, $(1-\overline{\theta}) = 0.10$, $\theta = 0.895$, $\alpha = 2.50$, $X_0 = 2.00$	X_t *collapses*

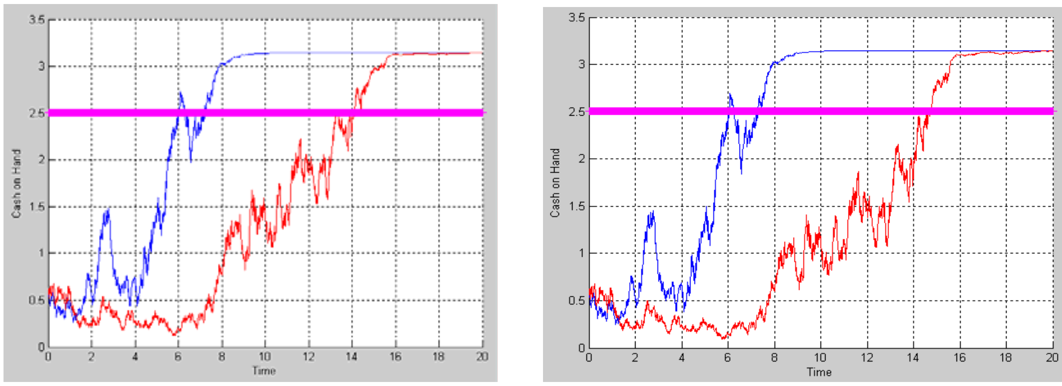

Figure 6. Some trajectories of X_t with capital accumulation. On the left hand side case #1, while on the right hand side is case #2. See Table 2.

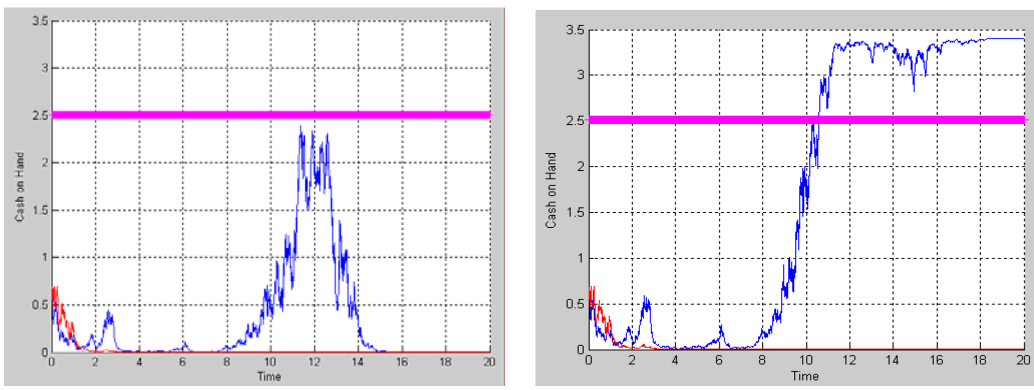

Figure 7. Some trajectories of X_t with capital accumulation. On the left hand side case #3, while on the right hand side is case #4. See Table 2.

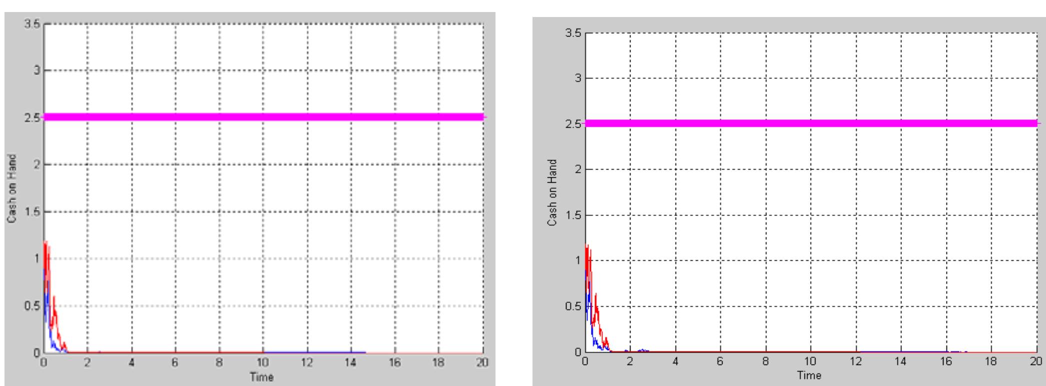

Figure 8. Some trajectories of X_t with capital accumulation. On the left hand side case #5, while on the right hand side is case #6. See Table 2.

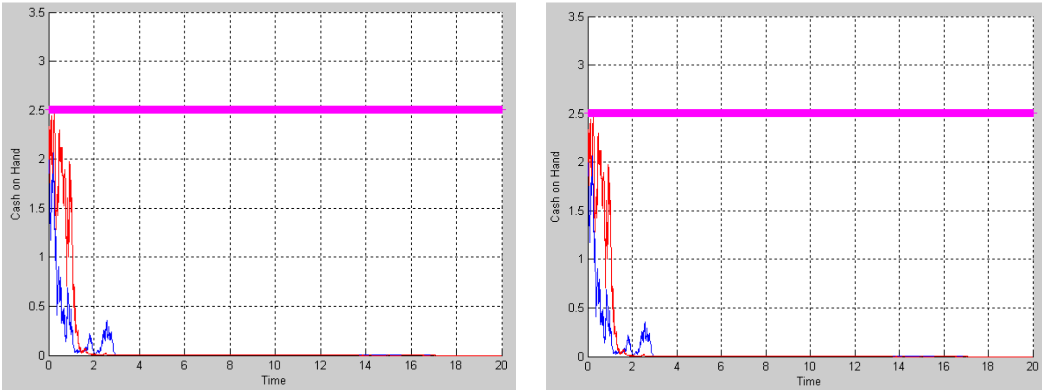

Figure 9. Some trajectories of X_t with capital accumulation. On the left hand side case #7, while on the right hand side is case #8. See Table 2

DISCUSSION

Compared to the deterministic approach used in Wibowo, D.H., Tisdell, C.A. and Byron, R.N. (1997), the above modeling provides further insights into farmer's capital accumulation behavior leads to forest clearing, if uncertainty is taken into account. It is shown that capital accumulation in the form of cinnamon plantation *always* results in farmers having adequate cash capital to clear a forest. In this Fokker-Planck modeling, however, such is not always the case. If the income process of the representative *anak ladang* follows the generalized Verhulst model, then only under certain conditions does capital accumulation give farmers a financial capability to clear a forest.

The first condition is that income uncertainty needs to be smaller than or equal to the proportion of cash on hand allocated into income-generating activities. Formally, this condition is represented by the $a \geq g^2$ case. As can be seen from Table 2 and Figure 6, the representative farmer is shown to be able to obtain adequate cash to clear a forest and establish a *ladang.* Nonetheless, Figure 6 also shown that some trajectories of the process X_t take longer than other trajectories does in reaching the "target boundary". If this result is generalized into the case of different individuals, it can be inferred that even with the same level of a and g^2, some farmers may reach the "target boundary" quicker than others due to the randomness of their income process.

Secondly, if the level of income uncertainty is such that it exceeds the proportion of cash on hand allocated into income-generating activities, then it is more likely than not that the representative farmer fails to reach the “target boundary”. In this case the farmer can still gain enough cash capital to clear a forest if his or her saving level is sufficiently high and the level of income uncertainty large. This condition is depicted by case #4 in Table 2 and Figure 7.

Nonetheless, if the level of uncertainty is sufficiently large, which in this simulation is represented by α = 2.5, the farmer in question tends to fail to read the “target boundary”. This means, the farmer will not have enough cash capital to clear a forest, even if his or her initial capital and/or saving level are increased significantly. In this simulation, increasing the initial capital by 3.57 times and the saving level by 3.33 times still fails to give the farmer necessary cash capital to clear forest and establish a *ladang.* Simulations of this are given by cases #5 to #8 in Table 2 and Figures 8 and 9.

The results also show that, regardless of the level of uncertainty, without capital accumulation the representative farmer cannot have adequate cash capital to clear forest. However, if the level of uncertainty is sufficiently larger than the proportion of cash on hand allocated into income-generating activities, the farmers may go bankrupt unless his or her initial capital is sufficiently large to prevent such a case from happening.

Another important result is that increasing the carrying capacity K by, for example, adopting a multi cropping system brings with it increased risks that the farmer’s income may collapse into a zero value. This is because a higher level of K, the income process does not have necessary strength to weather the “turbulence” of income uncertainty and reach the “safe” upper absorbing boundary. This result represents the fundamental rule of risky portfolios, that is, increased expected pay-offs are often associated with higher risks.

The model also sheds some light into how saving can be used as a precautionary means to cushion against uncertainty. With the absence of an agricultural insurance scheme, farmers can do little to reduce the uncertainty parameter α. However, to some degrees farmers can minimize g^2 by increasing their saving level. With reduced g^2, the probability of falling into the zero boundary also declines. Thus, increased saving can reduce the likelihood of farmers going bankrupt. As discussed earlier, however, higher saving level can become an effective cushion against uncertainty only if the uncertainty itself is not very large.

CONCLUSION

This chapter has shown how the Fokker-Planck equation and the simulation of stochastic trajectories can be used to explain capital accumulation and deforestation process. It is the exploitation of the boundary conditions associated with this equation that becomes the main tools in this analysis. However, use of the Fokker-Planck equation also gives a practical advantage in the sense that one can still construct a deforestation model even without optimizing the representative farmer's consumption behavior. The farmer's consumption behavior can also be treated as an arbitrarily determined parameter, for example by setting a given subsistence level. Thus, consumption optimization still provides many useful insights into deforestation behavior, such as how precautionary motives and preferences over farming land affect deforestation decisions.

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APPENDIX

Table 1. Distribution of Financial Returns Between Landowners and Anak Ladang from a Multicropping of Cinnamon and Potato (Rp/hectares) Upper kerinci Region, Indonesia.

Year	1	2	3	4	5	6	7	8	9	10	11	12
Flow for landowner												
(1:1 system)												
Farm inputs	-205,400	0	0	0	0	0	0	0	0	0	0	0
Living allowance for anak ladang	0	0	0	0	0	0	0	0	0	0	0	0
Value of potato share	0	0	0	0	0	0	0	0	0	0	0	0
Value of cinnamon share (one-half)	0	0	0	155,787	246,438	396,221	0	0	0	0	0	9,157,229
net flow	-205,400	0	0	155,787	246,438	396,221	0	0	0	0	0	9,157,229
Financial Flow for Anak Ladang												
Farm inputs	-5,556,343	-5,556,343	-5,556,343	-5,556,343	-5,556,343	-2,778,172	0	0	0	0	0	0
Value of potato share (100%)	9,605,628	9,605,628	9,605,628	9,605,628	9,605,628	4,802,814	0	0	0	0	0	0
Value of cinnamon share (one-half)	0	0	0	155,787	246,438	396,221	0	0	0	0	0	9,157,229
net flow	4,049,285	4,049,285	4,049,285	4,205,072	4,295,722	2,420,864	0	0	0	0	0	9,157,229

Table 2. Average Monthly Consumption of Anak Ladang [a)]

		Upper Region		Lower Region	
		Rp	**Share**	**Rp**	**Share**
A.	Cash Expenses				
	Staple food	33,182	37%	38,833	30%
	Other foods and beverages	22,091	25%	29,305	22%
	Sub Total				
	Other cash expenses b)	25,455	29%	45,403	35%
	Total cash expenses	80,727	91%	113,541	86%
B.	Consumption of own products				
	Staple food	6,545	7%	6,909	5%
	Other foods and beverages	1,530	2%	11,046	8%
	Total	8,075	9%	17,955	14%
C.	Total monthly consumption	88,803	100%	131,496	100%

Notes: a) Unusual big expenses such as wedding and purchase of a house or a motorcycle are not included
b) They include expenses for clothing, non-work related transports, kerosene, cigarettes, sanitary needs etc.

Table 3. Inputs and Output of a Hectare of Potato per Season under a Multicropping with Cinnamon, Upper Kerinci Region, Indonesia.

		Quantity	Price (Rupiah)	Total (Rupiah)
A.	Seeds (kgs)	874	670	585,826
B.	Fertilisers (kgs)			
	Urea (Nitrogen)	257	290	74,578
	TSP (Phosphate)	514	450	231,450
C.	Pesticides/Insecticides			
	Mixture (times of spraying)	57	17,000	961,803
D.	Transport Costs			
	Fertiliser delivery	15	2,250	34,718
	Output delivery	129	5,000	642,917
E.	Family Labour (days) a)	175	0	0
F.	Hired Labour (days)	62	4,000	246,880
G.	Total financial costs (A+B+C+D+F)			2,778,172
H.	Output			
	Large Size (SP quality)	7,540	546	4,116,909
	Medium Size (AB quality)	1,594	375	597,913
	Small Size (M quality)	468	188	87,992
	Total output value	9,603		4,802,814
G.	Financial surplus (H-G)			2,024,642

Notes :

a) For potato farming, non-harvesting and harvesting wages are equal.

Thus, no distinction is made between non-harvesting and hervesting labourers