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OPTIMAL LAND ALLOCATION UNDER IRREVERSIBLE LAND CONVERSION

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I. Introduction

As a result of the rapid transformation into an industrialized country, nonagricultural demand for land has persistently increased in Korea. The increasing nonagricultural demand for land has to be met mostly by a conversion of agricultural land since total available land is almost fixed. In order to convert agricultural land to nonagricultural land in a socially optimal manner, we must set up a conversion schedule of land. The primary purpose of this study is to derive a criterion to establish a socially optimal conversion schedule, emphasizing the role of irreversibility in land conversion.

One of the popular criteria for choosing the optimal land allocation is the net present value (NPV) method; if the current land allocation between agricultural and nonagricultural usages is at its optimal level, then the expected value of discounted sum of profits from each industry has to be identical. With uncertainty in production, the future values of agricultural and nonagricultural outputs are unknown at present time. Hence, decision making on land conversion has to be made knowing only the expected values of future profits.

Once we consider the irreversibility in land conversion, however, the NPV criterion may not be a rational criterion of land conversion. In general, it is much easier converting agricultural land

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to nonagricultural land than converting nonagricultural land to agricultural land[1] Suppose that actual profit obtained from the nonagricultural sector at a certain point of time turns out to be lower than that expected before. In this case, more than an optimal level of agricultural land would have been converted to nonagricultural land. However, irreversibility makes it impossible or very expensive to reconvert nonagricultural land. This possibility implies that we can obtain gains from postponing decision making under uncertainty and irreversibility since waiting provides better information. There is certain value in the unused option to convert agricultural land to nonagricultural land. Therefore, agricultural land needs to be converted in a more conservative way when irreversibility is properly incorporated in decision making. In other words, even though the expected value of discounted sum of profit from farming is smaller than that from the nonagricultural sectors, there still exists an economic incentive to preserve the current level of agricultural area.

This study derives a land conversion rule incorporating the impacts of irreversibility explicitly. The model is a variant of the resource allocation model between two sectors invented by Dixit (1989). This model allows to derive an analytical solution, and hence to compare the solutions with and without irreversibility explicitly. Dixit (1989) constructed a discrete model where the resource is converted by only an integer unit. This study generalizes Dixit (1989)'s model and constructs a model where land can be converted continuously. The study employs the theory of incremental investment developed by Pindyck (1988) or Dixit and Pindyck (1994) to derive the solution to the model.

The paper is organized as follows. The next section constructs a land conversion model where the nonfarm sector is subject to uncertain growth rate of land productivity. There is an incentive to

[1] Agricultural production is subject to various biological characteristics. Hence, it is very expensive, or it takes a long time to reconvert nonagricultural land to agricultural land. In addition, the values of the facilities built on nonagricultural land such as factories, commercial buildings and houses are much larger than those of agricultural facilities such as greenhouse. It is very costly to remove these nonagricultural facilities to convert current nonagricultural land to agricultural land.

convert agricultural land to nonagricultural land since the productivity grows faster in the nonfarm sector. The section derives optimal land conversion rule under irreversibility. Section Ⅲ extends the model and incorporates the impacts of the environmental benefits of farming into the model. It is shown that considering environmental benefits of farming results in more conservative land conversion compared with the case where neither irreversibility nor environmental aspects are considered. Further, it is shown that incorporating both irreversibility and environmental impacts into the model results in more conservative conversion compared with the case where only the environmental impacts are considered.

Ⅱ. The Model

Total land, L, is allocated to two sectors: agriculture, L-K and nonagriculture, K. Denote agricultural and nonagricultural outputs by X and Y, respectively. It is assumed that agricultural land is identical in terms of productivity and location. The agricultural production function is $F(L\text{-}K)$, a concave function of L-K. It is also assumed that land is the only input.

We assume that the economy is open, and the relative prices are fixed over time[2]. The price of food is one, and the price of nonagricultural good is fixed at A. Furthermore, we assume that the relative productivity in the nonfarm sector shifts over time[3]. Thus, the production function in the nonfarm sector is $PG(K)$, where $G(K)$ is another concave function, and P is the index of productivity in the nonfarm sector.

The only source of uncertainty in the model is P, which is the

[2] We can generalize the model and assume that the future prices are uncertain. The main conclusion of the model may not change even with this generalizing assumption. However, the model will be much more complicated, and it may not be possible to derive the analytical solutions to the model with this generalization.

[3] In Korea, the nonagricultural sector has been asking more conversion of agricultural land based on the fact that the productivity of the nonagricultural sector has grown faster than that of the farm sector (Oh 1993; Yang 1993). Our assumption incorporates this argument.

index of productivity in the nonfarm sector. The land productivity in the nonfarm sector grows faster than that in the farm sector on average, but the exact level of productivity in the future is not known. More specifically, we assume that the change in P follows a geometric Brownian motion.

$$\frac{dP_t}{P_t} = \alpha dt + \sigma dz_t, \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (1)$$

where α (> 0) and σ are parameters. z_t is a stochastic process:

$$dz_t = \varepsilon_t \sqrt{dt}, \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (2)$$

where ε_t is a normally distributed random variable with a mean of zero and a standard deviation of one[4]. Therefore, $E(dz) = 0$ and $E[(dz)^2] = dt$.

Under the above conditions, the change in $\ln(P)$ has a normal distribution. When time T elapses, the mean of the change in $\ln(P)$ is $(\alpha - \frac{1}{2}\sigma^2)$ T and its variance is $\sigma^2 T$. Thus, $E(P_t)$ changes over time following $E(P_t) = P_0 e^{\alpha t}$. P increases on average since α is positive.

The national revenue function is

$$R(K, P) = F(L\text{-}K) + PAG(K). \quad \cdots\cdots\cdots\cdots \quad (3)$$

Since each production function is concave,

$$R_{KK}(K,P) = F''(L\text{-}K) + PAG''(K) < 0.$$

Hence, R is also a concave function of K.

It is assumed that converting agricultural land into nonagricultural land is possible by paying the cost of τ per unit land. Since we seldom observe reconversion of nonagricultural land, we assume that the conversion to nonagricultural land is irreversible.

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4 Dixit and Pindyck (1994, pp. 68 - 70) and Dixit (1993, pp. 2 - 4) have shown that Brownian motion can be derived as the continuous limit of a discrete-time random walk.

The government is risk-neutral and maximizes the intertemporal sum of total revenue subtracted by the cost of conversion. Now, consider a short interval of time dt. The government wants to solve the following dynamic programming problem.

$$V(K,P) = \max R(K,P)dt + e^{-\rho dt}\{EV(K',P+dP) - \tau(K'-K)\}. \quad \cdots \quad (4)$$

K is the converted land at present time. K' is the area of converted land at the end of this interval. Under the condition of irreversibility, K' cannot be smaller than K ($K' \geq K$).

Consider two different initial levels of agricultural land, K_1 and K_2. Suppose that the optimal paths of converted land area are $\{K_{1t}\}$ and $\{K_{2t}\}$ with the initial area of K_1 and K_2 respectively, when the stochastic process P has the time path of $\{P_t\}$. Now consider another time path where $\theta K_{1t} + (1-\theta)K_{2t}$ ($\theta \in [0,1]$) is the area of nonagricultural land in each period. Since R is a concave function of K, we have the following relationship.

$$E\int_0^\infty R(\theta K_{1t} + (1-\theta)K_{2t}, P_t)e^{-\rho t}\,dt \geq$$

$$E\int_0^\infty \{\theta R(K_{1t}, P_t) + (1-\theta)R(K_{2t}, P_t)\}e^{-\rho t}\,dt.$$

Therefore, $V(K,P)$ is a concave function of K, and (4) can be solved through the familiar Kuhn-Tucker conditions.

Assuming an interior solution, take the differentiation of (4) with respect to K'. Then the derivative is

$$e^{-\rho dt}\{EV_K(K',P+dP) - \tau\}.$$

When dt approaches zero, the optimizing condition becomes

$$V_K(K,P) = \tau. \quad \cdots\cdots\cdots\cdots\cdots \quad (5)$$

Hence, we derive the following conversion rule:

① *If* $V_K(K,P) \leq \tau$, *there is no additional land conversion, i.e.,* $K' = K$.

② *If $V_K(K,P) > \tau$, then nonagricultural land increases until (5) holds, i.e., $K' > K$.* $\cdots\cdots\cdots\cdots$ (6)

The above decision making rule can be illustrated in the (K, P) space as shown by Figure 1. The curve in the figure is the locus of K and P which satisfies (5). The curve is upward-sloping since the benefit from conversion increases when P increases. In the figure, if the current (K, P) is located above the curve, then we have to increase K horizontally so that the combination of (K, P) is located on the curve. On the contrary, if the current position is below the curve, then too much land is being used for nonagricultural purposes. Since reconversion of land is not allowed, the current level of nonagricultural land has to be maintained in this case ($K'=K$).

Specific representation of the curve in Figure 1 can be derived by solving the dynamic programming model in (4). To begin, assume that the current combination of (K, P) is below the curve. In this case, $K' = K$, and (4) can be rewritten as

$$V(K,P) = R(K,P)dt + e^{-\rho dt}\{EV(K,P+dP)\}\ .$$

Expanding the right hand side using the Ito's lemma[5], and substituting the result yields the following nonhomogenous differential equation.

$$\frac{1}{2}\sigma^2 P^2 V_{PP}(K,P) + \alpha P V_P(K,P) - \rho V(K,P) + R(K,P) = 0. \quad \cdots \quad (6)$$

(6) is a partial differential equation. Since (6) does not involve any derivative with respect to K, however, the above equation can be treated as an ordinary differential equation that links V with P. Thus, K is assumed to be a constant. Since (6) is a linear differential equation, its general solution is composed of a complementary function and a particular solution.

[5] Ito's lemma can be understood as a Taylor series expansion of functions of random processes.

The particular solution can be derived using the following expected sum of revenue obtained when the current level of land allocation is maintained forever.

$$E \int_0^\infty R(K,P_t)e^{-\rho t}\, dt = \frac{PG(K)}{\rho-\alpha} + \frac{F(L-K)}{\rho} .$$

We assume $\rho > \alpha$ in order to obtain a nonnegative particular solution. Define the effective discount rate as $\delta = \rho - \alpha$.

Since (6) is a second order differential equation, its complementary function will be a linear combination of certain two functions. Following the existing similar models, we use the functional form, $C(K)P^{\beta}$. Hence, we can rewrite the value function, $V(K, P)$ as

$$V(K,P) = C_1(K)P^{\beta_1} + C_2(K)P^{\beta_2} + \frac{PG(K)}{\delta} + \frac{F(L-K)}{\rho}, \quad \cdots \quad (7)$$

where β_1 and β_2 are the roots of the following quadratic;

$$Q = \frac{1}{2}\sigma^2 \beta(\beta-1) + (\rho-\delta)\beta - \rho = 0 .$$

Define β_1 as the larger root. Since $\beta_1\beta_2 < 0$ and $(\beta_1-1)(\beta_2-1) < 0$, we know that $\beta_2 > 1$ and $\beta_2 < 0$.

The particular solution in (7) is the value of total discounted revenue when the initial land allocation is maintained. The complementary function is the value of holding the option to convert agricultural land to nonagricultural land. (1) shows that P will stay at 0 when its initial value is 0. Hence, when the initial value of P is 0, the value from holding the option to convert should be 0 as well. Since $\beta_2 < 0$, however, the value of complementary function is infinite when P approaches 0 as long as $C_2(K) \neq 0$. Therefore, we have to restrict $C_2(K)$ to be 0, and the final form of the value function is

$$V(K,P) = C_1(K)P^{\beta_1} + \frac{PG(K)}{\delta} + \frac{F(L\text{-}K)}{\rho} \quad \cdots\cdots\cdots\cdots \quad (8)$$

In order to derive the explicit functional form of the curve in Figure 1 from (8), we need two additional boundary conditions. The first condition that needs to hold on the curve is (5) which is called the value-matching condition. McDonald and Siegel (1986), Pindyck(1988), Dixit and Pindyck (1994: pp 130-132) have shown that we need the following smooth-pasting condition at the optimality which requires that the derivative of $V_K(K, P)$ with respect to P must equal the derivative of τ with respect to P as P increases to the curve:

$$V_{KP}(K,P) = 0. \quad \cdots\cdots\cdots\cdots \quad (9)$$

From the above three conditions (5), (8), and (9), the following solution is derived.

$$P(K) = \frac{\beta_1}{\beta_1\text{-}1}\frac{\delta}{AG'(K)}\left\{\tau + \frac{F'(L\text{-}K)}{\rho}\right\}, \quad \cdots\cdots\cdots\cdots \quad (10)$$

$$C'_1(K) = -\left[\frac{\beta_1\text{-}1}{\{\tau + F'(L\text{-}K)/\rho\}}\right]^{\beta_1\text{-}1}\left\{\frac{AG'(K)}{\beta_1\delta}\right\}^{\beta_1}. \quad \cdots\cdots \quad (11)$$

(10) is the explicit representation of the curve in Figure 1. If the current level of P is greater than the level which satisfies the relationship in (10) with given K, then the current land allocation is maintained. However, if current P exceeds the level which satisfies (10), then additional land will be transformed to nonagricultural land until (10) is satisfied. The following proposition compares the optimal land conversion schedules with and without irreversibility.

Proposition 1. The land conversion with irreversibility is slower than that without irreversibility.

Proof. When the area of converted land increases by dK during a certain interval of time the revenue from nonagricultural sector increases by $PAG'(K)dK$ instantaneously. Since the average growth rate of P is α, and the discount rate is ρ, the discounted sum of the increase in nonagricultural revenue is $PAG'(K)dK/\delta$. The cost to convert dK amount of land is τdK. Further, the decrease in agricultural revenue caused by the reduction in agricultural land is $F'(L\text{-}K)dK/\rho$. Hence, without irreversibility, additional land is converted if current P is greater than the level which satisfies the following relationship.

$$P(K) = \frac{\delta}{AG'(K)} \left\{ \tau + \frac{F'(L\text{-}K)}{\rho} \right\} \cdots\cdots\cdots\cdots \quad (12)$$

It has been shown that β_1 in (10) is greater than 1. Comparing (10) with (12) shows that additional land conversion occurs only if the gain from conversion in (10) is at least $\frac{\beta_1}{\beta_1 - 1}$ ($\rangle$ 1) times as large as the loss from conversion. Therefore, a land conversion is implemented more slowly under irreversibility. Q.E.D.

The following corollary shows the impacts of various parameters in the model on optimal land conversion rule.

Corollary 1. The impact of irreversibility on optimal land conversion is larger either when δ is smaller, or ρ is larger, or σ is larger.

Proof: (10) and (12) show that the land conversion with irreversibility relative to that without irreversibility is slower when $\frac{\beta_1}{\beta_1 - 1}$ is large. $\frac{\beta_1}{\beta_1 - 1}$ decreases in β_1, and Q is a convex function of β. Since β_1 is the larger root of Q, $\frac{\partial Q}{\partial \beta}\Big|_{Q=0} \rangle\, 0$. In addition, $\frac{\partial Q}{\partial \delta}$ <0, $\frac{\partial Q}{\partial \rho}$ >0, $\frac{\partial Q}{\partial \sigma^2}$ >0. Thus, $\frac{\beta_1}{\beta_1 - 1}$ decreases in δ, increases in ρ, and increases in σ by the implicit function theorem. Q.E.D.

The results of Corollary 1 are intuitive. If the effective discount rate δ is large (or if α is small), the future relative productivity of nonagricultural outputs increases more slowly. In this case, the value of holding option to convert land in the future is relatively small, and the speed of land conversion goes up. On the contrary, when σ is large the risk of carrying on nonagricultural business is large, and land is converted at a lower speed. Table 1 demonstrates the results numerically.

Table 1 confirms the results of Corollary 1, and shows the impacts of various parameters on the optimal land conversion rule. For instance, if the risk of conversion (α) is relatively large (0.5), and the effective discount rate (δ) is small (0.01), then additional land conversion occurs only if the expected gain from conversion is at least 23 times as large as the cost of conversion. Therefore, even though the productivity in the nonagricultural sector grows faster than that in the farm sector, the fact that the expected revenue from farming is much smaller than that from the nonagricultural business does not necessarily imply that more agricultural land has to be converted.

In order to get a more explicit schedule of land conversion, we impose some specific functional forms on the production functions. Assume that $G(K) = K^{\theta}$ and $F(L\text{-}K) = (L\text{-}K)^{\varphi}$. Furthermore, it is assumed that $A = 1.5$, $\tau = 0.01$, L = 100, $\theta = 0.8$, and $\varphi = 0.7$. Figures 2 and 3 depict $P(K)$'s in (10) and (12). Figure 2 assumes that $\sigma = 0.2$ and $\delta = 0.03$ while Figure 3 assumes that $\sigma = 0.5$ and $\delta = 0.01$. As shown by Table 1, the ratio between $P(K)$'s with and without irreversibility is much higher in Figure 3. Both figures show that the level of P which evokes additional land conversion under irreversibility has to be much higher than that without irreversibility.

TABLE 1 The Ratio between the Discounted Sums of Revenue from Agricultural and Nonagricultural Sectors

σ	δ	β_1	$\beta_1/(\beta_1-1)$
0.2	0.01	1.089	12.179
	0.02	1.192	6.193
	0.03	1.311	4.208
0.1	0.01	1.072	10.552
0.3		1.045	14.826
0.5		1.105	23.066

III. A Digression: The Impacts of Environmental Benefits of Farming

The previous section has shown that the NPV rule which compares the expected values of discounted sum of profits from each industry cannot be an appropriate criterion to set up a land conversion schedule when the land conversion is irreversible. It has been shown that considering irreversibility results in slower conversion of agricultural land.

Various authors (Wui et al. 1995, Oh et al. 1995, Ministry of Agriculture, Forestry and Fisheries et al. 1996) have recently pointed out the environmental benefits of farming as another reason for preserving agricultural land even if the profitability of agricultural land is lower than that of nonfarm land. These authors argued that the market value of agricultural output does not represent its true value because farming provides some extra benefits such as controlling water resources, purifying air and preventing soil erosion under the monsoon climates. That is, farming provides not only food whose value is evaluated in the market but also positive externalities to the society.

This section incorporates the environmental concerns into the model of previous section, and demonstrates that the model can be extended into the case where both environmental consideration and irreversibility are incorporated.

It is known that preserving a certain level of arable land generates environmental benefits. Incorporating such benefits, define a national utility function $U(R(K,P), L\text{-}K)$. The social welfare is obtained not only from revenue $R(K, P)$ but also from the land preserved for agricultural purposes, $L\text{-}K$. U is an increasing and concave function of $R(K, P)$ and $L\text{-}K$.

The discounted present value of utility obtained from maintaining the current land allocation can be calculated as

$$\bar{U}(K,P) = E\int_0^{\infty} U\,(R(K, P_t), L\text{-}K)e^{-\rho t}\,dt.$$

This discounted present value $\bar{U}$ has to replace the particular solution in (8), and the value function becomes

$$V(K,P) = C_1 (K)P^{\beta_1} + \bar{U}. \cdots\cdots\cdots\cdots \quad (8')$$

Furthermore, the value-matching condition (5) and the smooth-pasting condition (9) are written as

$$V_K(K,P) = C_1{}' (K)P^{\beta_1} + \bar{U}_K (K, P)$$
$$= C_1{}' (K)P^{\beta_1} + E\int_0^{\infty} [\, U_1 R_K - U_2 \,] e^{-\rho_1}dt = \tau \cdots\cdots \quad (5')$$

$$V_{KP} (K,P) = \beta_1 C_1{}' (K)P\beta_1\text{-}1 + U_{KP} (K,P)$$
$$= \beta_1 C_1{}' (K) P^{\beta_{-1}\text{-}1} + E\int_0^{\infty} [\, U_{11} R_p R_K + U_1 R_{KP} - U_{21} R_p] \, e^{-\rho_1} dt$$
$$= 0. \cdots\cdots\cdots\cdots\cdots \quad (9')$$

By solving (5') and (9') together, the following relationship between K and P is obtained.

$$\bar{U}_K (K,P(K)) - \frac{P(K)}{\beta_1} \bar{U}_{KP}(K, P(K)) = \tau. \cdots\cdots\cdots\cdots \quad (10')$$

(10') is the optimal relationship between K and P when both environmental benefits and the irreversibility in land conversion are incorporated. Suppose the environmental benefits of farming are considered, but irreversibility is ignored. Then, the following represents the optimal relationship between K and P.

$$\bar{U}_K (K,P(K)) = E\int_0^{\infty} (U_1 R_K - U_2)e^{-\rho_1} dt = \tau. \cdots\cdots\cdots \quad (13)$$

The authors who estimated the environmental benefits of preserving agricultural land may use (13) in order to derive the optimal land conversion rule.

Now consider the case where neither irreversibility nor environmental benefits of farming are taken into account. In this case, the government wants to maximize only the expected discounted sum of revenue. The optimizing condition becomes

$$E \int_0^{\infty} (U_1 R_K) e^{-\rho t} dt = \tau. \quad \cdots\cdots\cdots\cdots \quad (14)$$

In this case, both irreversibility and the contribution of agricultural land to welfare are ignored. (14) is the criterion that is often used by the nonfarm sectors to ask a faster relaxation of the regulations on land conversion.

Note $-U_2 < 0$. Therefore, when (13) holds $E \int_0^{\infty} (U_1 R_K) e^{-\rho t} dt > \tau$.

In other words, the expected increase in total revenue resulting from land conversion has to be greater than the loss from conversion when the environmental impacts are considered. Thus, when the environmental impacts are considered, conversion of agricultural land has to be slower compared with the case where neither irreversibility nor environmental impacts are considered.

Finally, suppose that (10') holds. Note $\bar{U}_K$ is the contribution of marginal land conversion to the discounted sum of expected utility. Since P is the index of relative productivity in the nonfarm sector, $\bar{U}_K$ increases in P ($\bar{U}_{KP} > 0$). Therefore, when (10') holds, $\bar{U}_K(K, P(K)) > \tau$. When both irreversibility and the environmental values of farming are incorporated, the expected increase in the discounted sum of utility resulting from land conversion has to be greater than the loss from conversion which includes the environmental damages caused by the loss of agricultural land.

Therefore, we have shown that the most conservative land conversion occurs when both irreversibility and the environmental benefits of farming are incorporated into the model. Considering only the environmental impacts will generate a faster conversion than the full model but a more conservative conversion than the case where neither effects are considered.

IV. Summary and Conclusion

We have constructed a land conversion model incorporating irreversibility in land conversion. It has been shown that there are incentives to preserve agricultural land even if the discounted sum of expected profit from nonfarm sector is greater than that from farming when irreversibility is properly considered.

The model in this study may provide some practical implications on the Korean land policy. The Korean agricultural land market has been under a strict government control. This strict regulation restricted the supply of land and has been pointed out as one of the major reasons for the rapid increase in land price. Thus, it has been argued that converting agricultural land to nonagricultural land should be allowed at least outside the Agricultural Promotion Area.

Answering this challenge[6] to the Korean land policy scheme, the Korean government has included land policy reforms to the Agricultural and Fisheries Development Plan in 1994. Under the new policy scheme, the government designates the Rural Industrial Zone where land owners can convert their land to industrial or residential sites without government's permission. Since it is widely observed that the land price in the Zone exceeds the expected sum of discounted profit from farming, most land in the Zone is expected to be converted to nonagricultural land.

Since the Korean economy is rapidly transforming to an industrialized one, the demand for agricultural land by nonagricultural sectors will increase over time. Hence, it is likely that the Rural Industrial Zone will expand as time elapses, and the government would like to establish a schedule of land conversion and the optimal size of the Zone in each period. We argue that irreversibility analyzed by this study has to be an important element in establishing the schedule.

In order to construct a more realistic model, we can extend the model into various directions. First, we can introduce some other productive inputs such as labor and capital into the model, and it may be possible to investigate optimal migration of labor or intersectoral

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[6] Another challenge arose within the agricultural sector. Since nonagricultural demand for land is very strong, the land price will be much higher than the expected value of earning from farming when land conversion is allowed. Thus, some farmers have strongly asked to allow conversion of their land so that they can gain from selling their land to nonagricultural buyers. Various issues surrounding land policy have been reviewed by Lee (1994) and Kim (1996).

allocation of capital under irreversibility. Second, we can assume that not only the relative productivity of the nonfarm sector but also the future relative prices are uncertain. The techniques used in the study can be applied to the model with multiple random processes. Third, we may be able to introduce some differences in land quality. In reality, productivity of land is not identical. Furthermore, the location of land is an important element of land price. It may be rational to convert agricultural land less productive for farming and closer to urban areas. Hence, more realistic model has to contain the impacts of land quality and locational elements. Fourth, instead of geometric Brownian motion, we can employ some other random processes such as mean-reverting or jump processes for the change in relative productivity index. Finally, we assumed that the expected relative productivity index in the nonfarm sector can grow infinitely. If this assumption is unrealistic, then we can specify an upper limit of the productivity index and derive the conversion rule under the limit.

However, all these generalizations will make the analysis much more complicated, and it may not be possible to derive an analytical solution to the model. Hence, we have to resort to numerical methods to get the solutions to the generalized models.

FIGURE 1 Land Conversion Under Irreversibility

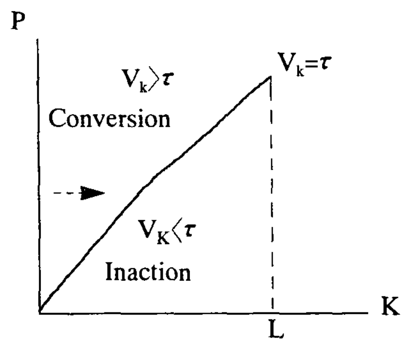


FIGURE 2 P(K)'s with and without Irreversibility: σ = 0.2, δ = 0.03

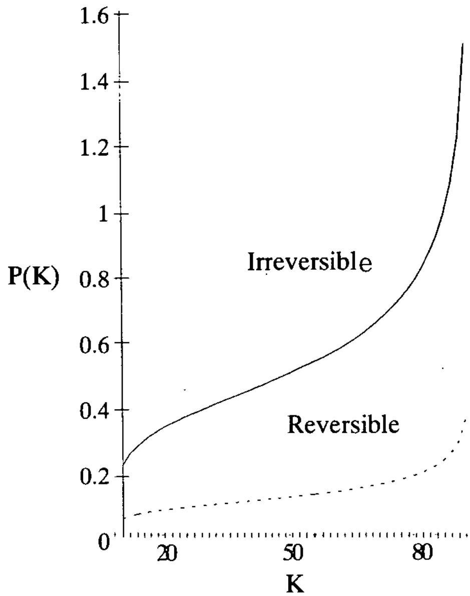
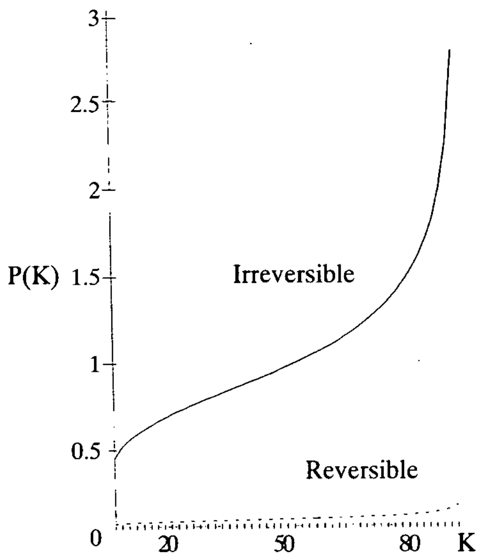


FIGURE 3 P(K)'s with and without Irreversibility: σ = 0.5, δ = 0.01



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