Journal of the Korean Geographical Society
Vol. 31, No. 4, 1996, 648-661

Behavior in Agricultural Markets under Environmental Uncertainty: A Theoretical Approach Based on von Thünen's Framework

Sang-Yool Lee* and Gordon F. Mulligan**

The traditional von Thünen model has various shortcomings. Perhaps the greatest deficiency is the model's sole emphasis on the production side of the economy; that is, the agricultural markets are rarely closed for demand. In this paper a closed model for a three-activity, two-dimensional economy is developed. Equilibrium solutions are generated for prices, land areas, and outputs. Comparative static analysis then follows. Attention is next given to a maximum expected-return model under environmental uncertainty. Land uses for the traditional model and the closed model are then compared.

Key Words: von Thünen model, closed model, comparative statics, environmental uncertainty, land uses.

1. Introduction

Agricultural location theory, drawing upon the early ideas of Ricardo and von Thünen, seeks to explain the geographic distribution of agricultural activities. As reviewed by Kellerman (1989a, 1989b), the theroy has been applied to many cases in the real world; furthermore, the theory itself has been developed much since Dunn (1954). This paper focuses on the theory of the von Thünen model, first introducing market demand, whose absence can be regarded as the most serious deficiency of the traditional model. Then the analysis of the paper turns to environmental uncertainty, and equilibrium land uses are identified for both the traditional model and the closed model. All results are based on the assumption that farmers strive to maximize their averaged return on land over the long run.

Von Thünen's analysis of agricultural activities in the Isolated State is basically descriptive rather than normative (Harvey, 1966). His analysis was later developed as a normative model by Hoover (1948), Lösch (1954), Dunn (1954), and Isard (1956). The main feature of the normative model is that economic rent declines with distance from the market town because transportation cost increases with distance, with the added assumption that other input variables, such as average cost per unit of output, average yield per unit of land, and market price, are constant at any location. A market town is acknowledged as a focal point for the saptial allocation of all agricultural crops. That is, this town is designated as a fixed point in space and assumed to be a selling place for agricultural products. In fact, though, the market town has importance more than just location: it functions as a clearing mechanism for all agricultural markets. This property has not been

*Ph.D. Candidate, Department of Geography and Regional Development, University of Arizona
**Professor, Department of Geography and Regional Development, University of Arizona

considered in traditional versions of the von Thünen model. Therefore, the traditional version of the von Thünen model can be referred to as only a production-oriented model.

The best known analysis of the von Thünen model is that of Dunn (1954) who explained the spatial equilibrium process of agricultural land use. As he pointed out, the traditional interpretation of von Thünen"s analysis is a partial equilibrium model where all land-use decisions are based on exogenous market prices. While Dunn acknowledged that market demand should be considered for each agricultural activity, he never did demonstrate how to operationalize closure of the model. Consequently, the traditional von Thnen model for agriculture, with its sole emphasis on production or supply, must be considered seriously deficient as a predictive tool.

2. The Production-Oriented Model

The analysis employs several well known and acceptable assumptions. The two-dimensional economy is assumed to be isotropic where environmental conditions and transportation rates are the same everywhere. All agricultural produce is shipped to a market town located in the center of the economy. Mobility of all factors is assumed to be perfect and all production units (points in space) exhibit constant returns to scale.

Yield, price, non-land production cost, and the transportation rate for activity i are denoted by E_i, p_i, a_i, and f_i, respectively. Then the rent $R_i(k)$ earned at distance k from the market is

$$R_i(k) = E_i(p_i - a_i) - E_if_ik = R_i(0) - T_ik \qquad (1)$$

where $R_i(0)$ is the rent level at the market town (here k =0) and T_i, the transportation cost per unit area per unit of distance for each commodity, is the slope of the rent gradient. The distance from the market town where the rent level for activity i is zero can be shown to be

$$k_{i,\max} = (p_i - a_i)/f_i = R_i(0)/T_i \qquad (2)$$

which indicates activity i's extensive margin, spatial margin, or economic limit.

Throughout this paper, it is considered that there are three competing activities (or crops), i =3, for land. In order to satisfy ordering conditions, assume that crop 1 dominates the land closest to the market, crop 2 dominates the land next to the land for crop 1, and crop 3 dominates the land furthest from the market. Adapting the argument of Dunn (1954), the intercepts of the rent gradients are ordered $E_1(p_1 - a_1)$ $(E_2(p_2 - a_2)$ $(E_3(p_3 - a_3) > 0$ and the slopes of the rent gradients are ordered $E_1f_1 > E_2f_2 > E_3f_3$. These conditions ensure that the three activities are ordered from the steepest to the least steepest away from the market town and, of course, only those situations where $R_i(k) \geq 0$ are of interest. These conditions also ensure that the rent gradients intercept so that circular zones of domination occur around the market town. The distances k_{12}, k_{23}, and $k_{3,\max}$, indicating boundary points for these zones, are determined by equating the economic rent earned by adjacent crops. That is, k_{12} is obtained by setting $R_1 = R_2$:

$$k_{12} = [E_1(p_1 - a_1) - E_2(p_2 - a_2)]/(E_1f_1 - E_2f_2) \qquad (3a)$$

while k_{23} is solved by setting $R_2 = R_3$:

$$k_{23} = [E_2(p_2 - a_2) - E_3(p_3 - a_3)]/(E_2f_2 - E_3f_3) \qquad (3b)$$

Finally, $k_{3,\max}$, the extensive margin of production for activity 3, is determined by setting the rent for that activity equal to zero:

$$k_{3,\max} = (p_3 - a_3)/f_3 \qquad (3c)$$

Consequently, crop 1 is grown from 0 to k_{12}, crop 2 is grown from k_{12} to k_{23}, and crop 3 is grown from k_{23} to $k_{3,\max}$. In the two-dimensional case, the cultivation area of each crop can be obtained by applying simple geometry. The distances k_{12}, k_{23}, and $k_{3,\max}$ are the radii of the circles representing the outer boundaries of each cultivation zone. The areas dominated by the three activities are of the following size:

$$A_1 = \pi k_{12}^2 \qquad (4a)$$
$$A_2 = \pi(k_{23}^2 - k_{12}^2) \qquad (4b)$$
$$A_3 = \pi(k_{3,\max}^2 - k_{23}^2) \qquad (4c)$$

and the outputs (quantities supplied) of the three crops are as follows:

$$Q_1^s = E_1A_1 \quad (5a)$$
$$Q_2^s = E_2A_2 \quad (5b)$$
$$Q_3^s = E_3A_3 \quad (5c)$$

To numerically illustrate these properties, consider the following parametric values (in appropriate units) shown in Table 1. From the above equations, the rents earned at the market town are $R_1(0) = 55$ for crop 1, $R_2(0) = 20$ for crop 2, and $R_3(0) = 5$ for crop 3. The slopes of the rent gradients are $T_1 = 4$, $T_2 = 0.5$, and $T_3 = 0.05$.

Crop 1 dominates the area from $k = 0$ to $k_{12} = 10$, crop 2 dominates from $k_{12} = 10$ to $k_{23} = 33.33$, while crop 3 dominates from $k_{23} = 33.33$ to $k_{3,max} = 100$. Consequently, the areas dominated by the three activities are $A_1 = 100.0\pi$, $A_2 = 1{,}011.1\pi$, and $A_3 = 8{,}888.9\pi$, and the three outputs are $Q_1 = 2{,}000.0\pi$, $Q_2 = 10{,}111.1\pi$, and $Q_3 = 44{,}444.5\pi$.

The production-oriented model assumes the independency of the four parameters E_i, p_i, a_i, and f_i. Such an assumption is not characteristic of real economic conditions, even for an abstract, simplified model, and the interrelationships of all factors influencing the spatial distribution of land use cannot be understood. Moreover, this assumption of parametric independence can lead directly to erroneous comparative static predictions. In particular, the price parameters are assumed to be exogenously set at the market town. When any other parameters are assumed to shift, none of the three prices is allowed to respond in the production-oriented model. This is quite an unreasonable property for an economic model.

This unreasonable assumption can be systematically illustrated within the production-oriented model. If the price of each crop is derived from equations (3a), (3b), and (3c), parametric dependency on the supply side of the model can be identified as follows:

$$\begin{bmatrix} p_1 \\ p_2 \\ p_3 \end{bmatrix} = \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix} + \begin{bmatrix} 1/E_1 & 1/E_1 & E_3/E_1 \\ 0 & 1/E_2 & E_3/E_2 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} (E_1f_1 - E_2f_2)k_{12} \\ (E_2f_2 - E_3f_3)k_{33} \\ f_3k_{3,\max} \end{bmatrix} \quad (6)$$

Equation (6) indicates that the price p_1 of crop 1 is a function of seven other parameters, the price p_2 of crop 2 a function of five other parameters, and the price p_3 of crop 3 a function of two other parameters when the radii k_{12}, k_{23} and the extensive margin $k_{3,\max}$ are known.

Unfortunately, most previous studies based on the production-oriented model have not noted this interdependency between the parameters. Jones (1978), who constructed a model regarding rent change in supply and demand interaction, disregarded it by assuming that prices are determined at the national scale. Even when some parametric interdependency in the production-oriented model has been recognized (Cromley 1982), the underlying mechanism for this interdependency has been rarely clarified.

Besides this underlying structural problem of the production-oriented model, the validity of the model with regard to the role of demand has been questioned by A. Jones et al. (1978) and, more recently, Samuelson (1983) and Nerlove and Sadka (1991). They have pointed out that von Thnen did not acknowledge an active role for market demand in determining bid rent, and that the traditional model implicitly assumes all market demand is perfectly inelastic.

Table 1. Input Data*

	Crop 1	Crop 2	Crop 3
Yield (E_i)	20	10	5
Price (p_i)	6	4	5
Production Cost (a_i)	3.25	2.00	4.00
Transportation Rate (f_i)	0.20	0.05	0.01

* Appropriate units for these parameters might be bushels per acre (yield), dollars per bushel (price, production cost), and dollars per bushel per mile (transportation rate).

3. Closed Model

The analysis assumes that market demand for each activity is linear in price. Current research provides only partial equilibrium and not general equilibrium solutions for activity prices, land areas, and outputs, because later in the paper concern turns to varying yields under different environmental conditions. By not formally introducing a production function for each activity, the analysis remains manageable.

To begin with, a general market demand function for crop i can be specified as follows:

$$Q_i^d = f(p_1, p_2, ..., p_n, P, I, T) \quad (7)$$

where Q_i^d is the quantity demanded of crop i, p_1, p_2, ..., p_n are the prices of the n crops in the market, and P, I, and T denote the population of the market town, and the income and tastes of that population, respectively. This general demand equation is simplified to a linear relationship between the quantity demanded of a particular crop and the prices for all crops, holding constant population size, income, and tastes. Consider the following three demand curves:

$$Q_1^d = \alpha_1 - \beta_{11}p_1 - \beta_{12}p_2 - \beta_{13}p_3 \quad (8a)$$

$$Q_2^d = \alpha_2 - \beta_{21}p_1 - \beta_{22}p_2 - \beta_{23}p_3 \quad (8b)$$

$$Q_3^d = \alpha_3 - \beta_{31}p_1 - \beta_{32}p_2 - \beta_{33}p_3 \quad (8c)$$

where the intercepts α_1, α_2, and $\alpha_3 > 0$, the coefficients for the in-market effect β_{11}, β_{22}, and $\beta_{33} > 0$, and the coefficients for the cross-market effect β_{12}, β_{13}, β_{21}, β_{23}, β_{31}, and $\beta_{32} \geq 0$. In turn, each of these equations can be easily transformed into a linear relationship between the price of a particular crop and the quantities demanded of all crops. That is, the three demand relationships can be respecified as:

$$p_1 = \delta_1 - \lambda_{11}Q_1^d - \lambda_{12}Q_2^d - \lambda_{13}Q_3^d \quad (9a)$$
$$p_2 = \delta_2 - \lambda_{21}Q_1^d - \lambda_{22}Q_2^d - \lambda_{23}Q_3^d \quad (9b)$$
$$p_3 = \delta_3 - \lambda_{31}Q_1^d - \lambda_{32}Q_2^d - \lambda_{33}Q_3^d \quad (9c)$$

where the same ordering conditions hold on the intercept, own-demand, and cross-demand terms. Equations (8a) and (9a), equations (8b) and (9b), and equations (8c) and (9c) are simply linear transformations of one another. In order to express the interconnection between supply and demand in this paper, however, the versions given in equations (9a), (9b), and (9c) are easier to use, and are therefore adopted for the analysis.

In order to construct a closed von Thnen model, each of the quantities Q_1^d, Q_2^d, and Q_3^d demanded in the market is set equal to its counterpart among the quantities Q_1^S, Q_2^S, and Q_3^S supplied Then, after the substitution of Q1d, Q_2^d, and Q_3^d into equations (9a), (9b), and (9c), the following market-clearing expressions for the three crops can be determined by equating each price in equation (6) with the appropriate price in each of the demand curves:

$$\delta_1 - (\lambda_{11}E_1 - \lambda_{12}E_2)\pi k_{12}^2 - (\lambda_{12}E_2 - \lambda_{13}E_3)\pi k_{23}^2 - \lambda_{13}\pi E_3 k_{3,\max}^2 = a_1 + \{(E_1 f_1 - E_2 f_2)k_{12} + (E_2 f_2 - E_3 f_3)k_{23} + E_3 f_3 k_{3,\max}\}/E_1 \quad (10a)$$

$$\delta_2 - (\lambda_{21}E_1 - \lambda_{22}E_2)\pi k_{12}^2 - (\lambda_{22}E_2 - \lambda_{23}E_3)\pi k_{23}^2 - \lambda_{23}\pi E_3 k_{3,\max}^2 = a_2 + \{(E_2 f_2 - E_3 f_3)k_{23} + E_3 f_3 k_{3,\max}\}/E_2 \quad (10b)$$

$$\delta_3 - (\lambda_{31}E_1 - \lambda_{32}E_2)\pi k_{12}^2 - (\lambda_{32}E_2 - \lambda_{33}E_3)\pi k_{23}^2 - \lambda_{33}\pi E_3 k_{3,\max}^2 = a_3 + f_3 k_{3,\max} \quad (10c)$$

The two radii of indifference k_{12}, k_{23} and the extensive margin $k_{3,\max}$ cannot be directly computed from the above equations. Instead an iterative-solution method is used to calculate the approximate values of k_{12}, k_{23}, and $k_{3,\max}$. Initially, arbitrary values are assigned to k_{12}, k_{23}, and $k_{3,\max}$, and then the iterative process is repeated until the values converge on stable values within an acceptable tolerance level (0.00001). After the indifference radii and the extensive margin are obtained, they are used to calculate the dominant areas of the three crops in equations (4a), (4b), and (4c). Then the equilibrium prices p_1, p_2, and p_3 in each agricultural market can be derived through either the price vector of equation (6) or equations (9a), (9b), and (9c). The equilibrium outputs Q_i are simply obtained by multiplying together the appropriate yield E_i per unit area and the appropriate land area A_i of each crop, as shown in equations (5a), (5b), and (5c).

4. Comparative Static Analysis

Having considered the two versions of the von Thnen model, comparative static analysis is used to examine changes in the equilibrium status of each model. The purpose of comparative static analysis is to discern whether small parametric shifts have implications for the equilibrium of a model. In particular, if many variables are interrelated and, therefore, causal paths are difficult to distinguish, the technique of comparative statics is very useful. However, this analysis does not always accurately expose the process of adjustment as the economy moves from one equilibrium state to another. A quantitative approach in comparative statics, which focuses both on the direction and magnitude of movement of numerical properties, is adopted rather than the preferred qualitative approach, which is concerned with the signs of derivatives. In this section, values for prices, outputs, and land areas are simulated for both versions of the von Thünen model and movements of these key variables are traced through comparative static analysis.

However, prior to such analysis, demand parameters must be given for each of the three activities. Values for the intercepts δ_i and the slope coefficients λ_{ij} of equations (9a), (9b), and (9c), are exogenously provided in Table 2.

In order to construct reasonable demand curves, the coefficients for the in-market effects in all three activities are made much larger than the coefficients for the cross-market effects, which can be regarded as substitution effects. Note in Table 2 that the in-market effect for crop 1 is much larger than the in-market effect for either of the other two crops, indicating that the price of crop 1 is especially sensitive to the quantity demanded of that crop.

Table 2. Exogenous Intercepts and Coefficients

	Intercepts(δ_i)	Coefficients(δ_{ij})		
		λ_{i1}	λ_{i2}	λ_{i3}
Crop 1	10	$1/500\pi$	$1/25,000\pi$	$1/95,000\pi$
Crop 2	6	$1/25,000\pi$	$1/7,500\pi$	$1/150,000\pi$
Crop 3	5	$1/95,000\pi$	$1/550,000\pi$	$1/65,000\pi$

1) Transportation Rates

The geographic distribution of economic rent in both the traditional model and the closed model depends intimately on the transportation rate for each crop. Consequently, the different transportation rates act as determining parameters in the spatial allocation of crops. Leaman and Conkling (1975) have empirically studied the impact of a transportation rate change on an agricultural production system and they concluded that a rate decline induces increasing degrees of agricultural specialization. Peet (1969) has also associated declining transportation rates in the von Thnen model with the spatial expansion of agriculture.

Table 3 shows comparative equilibrium solutions for both versions of the von Thnen model based on the data given in Tables 1 and 2. In both cases the transportation rate f_1 for activity 1 is decreased in steps of 0.05 from 0.25 to 0.15, holding all other variables constant.

In the production-oriented model none of the

Table 3. The Effect of Changes in the Transportation Rate (crop 1)

	Production-Oriented Model			Closed Model		
	f_1 =0.25	f_1 =0.20	f_1 =0.15	f_1 =0.25	f_1 =0.20	f_1 =0.15
p_1	6.0000	6.0000	6.0000	6.2350	5.8848	5.4899
p_2	4.0000	4.0000	4.0000	4.0404	4.0417	4.0433
p_3	5.0000	5.0000	5.0000	4.6959	4.6952	4.6943
k_{12}	7.778	10.000	14.000	8.731	9.223	9.748
k_{23}	33.333	33.333	33.333	37.610	37.648	37.690
$k_{3,\max}$	100.000	100.000	100.000	69.590	69.516	69.433
A_1	60.5π	100.0π	196.0π	76.2π	85.1π	95.0π
A_2	$1,050.6\pi$	$1,011.1\pi$	915.1π	$1,338.3\pi$	$1,332.3\pi$	$1,325.5\pi$
A_3	$8,888.9\pi$	$8,888.9\pi$	$8,888.9\pi$	$3,428.3\pi$	$3,415.1\pi$	$3,400.4\pi$
Q_1	$1,201\pi$	$2,000\pi$	$3,920\pi$	$1,525\pi$	$1,701\pi$	$1,900\pi$
Q_2	$10,560\pi$	$10,111\pi$	$9,151\pi$	$13,383\pi$	$13,323\pi$	$13,255\pi$
Q_3	$44,445\pi$	$44,445\pi$	$44,445\pi$	$17,141\pi$	$17,076\pi$	$17,002\pi$

three prices is affected by a change in transportation rate. Note that as f_1 declines the point of indifference k_{12} shifts outward while k_{23} and $k_{3,max}$ remain fixed, reflecting a rotational shift in the rent gradient for activity 1. Consequently, the land given to activity 1, as well as the output of activity 1, increases dramatically while the land given to activity 2, as well as the output of activity 2, declines. Activity 3 is not affected by this shift in f_1. However, in the closed model the situation is more complicated. Decreases in the transportation rate for activity 1 lead to dramatic decreases in the equilibrium price for that same activity, while the prices for activities 2 and 3 are only marginally shifted. The point of indifference k_{12} is again shifted outward, but not to the extent predicted by the production-oriented model. From the various simulations, it should be apparent that the traditional model overpredicts the amount of land that is switched out of activity 2 into activity 1 with any decrease in f_1. It should also be pointed out that while this specific rate change does not reduce the total area of agriculture in the production-oriented model, the total area is certainly reduced in the closed model.

2) Non-land Production Costs

A shift in the non-land production costs can also be compared in the two versions of the von Thnen model. Like the changes in the transportation rate analyzed for activity 1 above, the non-land production costs for this activity a_1 are now varied as follows: a_1 =4.0, 3.5, and 3.0. The results of the consequent simulations are shown in Table 4.

As in the case earlier, the three prices in the production-oriented model are not affected by this change in non-land production cost. The point of indifference k_{12} is moved dramatically outward due to any decrease in the production cost, as a parallel shift outward in the rent gradient for activity 1 takes place. However, k_{23} and $k_{3,max}$ remain fixed. As a result, the land area given to activity 1 is expanded while the land area devoted to activity 2 is reduced; the land in activity 3 is not affected at all. In the closed model, however, different equilibrium prices are generated for each activity depending upon the level of a_1. In particular, the price p_1 decreases considerably as the cost a_1 decreases, while the other two equilibrium prices are only marginally affected. Decreases in the non-land production cost again induce an expansion of the land area A_1 devoted to activity 1; as in the previous case, however, the responses are less dramatic than those in production-oriented model. In other words, comparative static changes in land uses and outputs are overpredicted in the traditional version of the von Thnen model.

3) Yields

In agricultural history, technological advance-

Table 4. The Effect of Changes in Non-land Production Cost (crop 1)

	Production-Oriented Model			Closed Model		
	$a_1 = 4.00$	$a_1 = 3.50$	$a_1 = 3.00$	$a_1 = 4.00$	$a_1 = 3.50$	$a_1 = 3.00$
p_1	6.0000	6.0000	6.0000	6.4838	6.0858	5.6829
p_2	4.0000	4.0000	4.0000	4.0394	4.0410	4.0425
p_3	5.0000	5.0000	5.0000	4.6964	4.6956	4.6947
k_{12}	5.714	8.571	11.429	8.364	8.944	9.495
k_{23}	33.333	33.333	33.333	37.583	37.626	37.670
$k_{3,max}$	100.000	100.000	100.000	69.643	69.559	69.474
A_1	32.7π	73.5π	130.6π	70.0π	79.8π	90.2π
A_2	$1,078.5\pi$	$1,037.6\pi$	980.5π	$1,342.5\pi$	$1,335.7\pi$	$1,328.9\pi$
A_3	$8,888.9\pi$	$8,888.9\pi$	$8,888.9\pi$	$3,437.7\pi$	$3,422.7\pi$	$3,407.0\pi$
Q_1	653π	$1,469\pi$	$2,612\pi$	$1,399\pi$	$1,600\pi$	$1,803\pi$
Q_2	$10,785\pi$	$10,376\pi$	$9,805\pi$	$13,425\pi$	$13,357\pi$	$13,289\pi$
Q_3	$44,445\pi$	$44,445\pi$	$44,445\pi$	$17,188\pi$	$17,114\pi$	$17,038\pi$

ment has been a major factor in enhancing crop productivity; environmental influences, on the other hand, cause variations in crop yields from one year to the next. These environmental influences on yield variation will be taken up in the next section of the paper. Now the case of yield change for a single crop is examined in both versions of the von Thnen model. Simulations can be related to those historical situations where productivity increases have not occurred for all crops at the same time. To illustrate such change, the yield of crop 1 is increased from $E_1 = 20$ to $E_1 = 30$ in two equal steps, where other variables are again held constant. Like the two earlier cases, the results of these small yield shifts are illustrated in Table 5.

In the production-oriented model a yield change for a crop creates a simple rotational shift in the slope of that crops rent gradient. Consequently, the land area allocated to crop 1 is increased by any increase in E_1. However, in the closed model the resulting change is much more complicated in nature: here the effect is opposite and any yield increase actually induces a decrease in the land allocated to crop 1. All three equilibrium prices decline in the closed model, but this price reduction is greatest for crop 1. Since all three agricultural markets are closed for demand in the latter case it is interesting to note how yield changes affect the total amount of land given over to agriculture. Note that the total land area is marginaally reduced from 4832.5π units for $E_1 = 20$ to 4805.8π units for $E_1 = 30$.

4) Demand Properties

In a sense the three previous cases have highlighted changes in the supply characteristics of the agricultural economy. Now interest turns to the case of how market demand affects equilibrium solutions; of course, this can only be addressed in the closed model. Dunn (1954), for one, discussed the nature of demand for agricultural products in his classic study of the von Thnen model. He considered three different determinants of demand, as mentioned earlier in the paper: (1) population size of the market town, (2) the preferences or tastes of the town residents, and (3) the income of these residents. Never, however, did he show the effects of demand shifts in the von Thnen model. Here the comparative statics of market demand are examined using three scenarios of the closed model.

The first scenario, using input data from Table 2, serves as a baseline for the other two cases. In the second scenario, the intercept term δ_2 of equation (9b) is changed from 6 to 8, thereby producing a parallel shift outward in the demand curve for crop 2. This might result from an increase in the population of the market town. In the third scenario, a change is made in the in-market coefficient of demand for crop 2 from $\lambda 22 = 1/10000\pi$ to $\lambda_{22} = 1/7500\pi$. This might represent a change in either the income or tastes

Table 5. The Effect of a Yield Increase (crop 1)

	Production- Oriented Model			Closed Model		
	$E_1 = 20$	$E_1 = 25$	$E_1 = 30$	$E_1 = 20$	$E_1 = 25$	$E_1 = 30$
p_1	6.0000	6.0000	6.0000	5.8848	5.6081	5.4018
p_2	4.0000	4.0000	4.0000	4.0417	4.0350	4.0298
$p3$	5.0000	5.0000	5.0000	4.6952	4.6941	4.6932
k_{12}	10.000	10.833	11.364	9.223	8.578	8.047
k_{23}	33.333	33.333	33.333	37.648	37.509	37.403
$k_{3,max}$	100.000	100.000	100.000	69.516	69.406	69.323
A_1	100.0π	117.4π	129.1π	85.1π	73.6π	64.8π
A_2	$1{,}011.1\pi$	993.7π	982.0π	$1{,}332.3\pi$	$1{,}333.3\pi$	$1{,}334.5\pi$
A_3	$8{,}888.9\pi$	$8{,}888.9\pi$	$8{,}888.9\pi$	$3{,}415.1\pi$	$3{,}410.3\pi$	$3{,}406.5\pi$
Q_1	$2{,}000\pi$	$2{,}934\pi$	$3{,}874\pi$	$1{,}701\pi$	$1{,}840\pi$	$1{,}943\pi$
Q_2	$10{,}111\pi$	$9{,}938\pi$	$9{,}820\pi$	$13{,}323\pi$	$13{,}333\pi$	$13{,}342\pi$
Q_3	$44{,}445\pi$	$44{,}445\pi$	$44{,}445\pi$	$17{,}076\pi$	$17{,}051\pi$	$17{,}033\pi$

Table 6. The Effect of Changes in Demand

Scenario	P_1	P_2	P_3	Q_1	Q_2	Q_3	k_{12} (Area 1)	k_{23} (Area 2)	$k_{3,max}$ (Area 3)
1	5.8848	4.0417	4.6952	1,701π	13,323π	17,076π	9.223(85.1π)	37.648(1,332.3π)	69.516(3,415.1π)
2 (δ_2)	6.0334	4.6130	4.7268	1,424π	24,279π	13,915π	8.43(71.2π)	49.992(2,428.0π)	72.678(2,783.0π)
3 (λ_{22})	5.9312	4.2074	4.7035	1,625π	16,193π	16,245π	9.014(81.3π)	41.237(1,619.2π)	70.353 (3,249.1π)

of the residents of the market town. In both cases all other parameters of the model are held constant. The results of these simulations are shown in Table 6.

In scenario 2, the shift in the intercept term induces great changes in the equilibrium solutions for prices, land areas, and outputs. As the demand curve for crop 2 shifts outward, the land allocated to activity 2 increases while the land given to both crops 1 and 3 decreases. Total land area is, though, increased from 4832.5π units to 5282.2π units. The equilibrium prices of all three crops are shifted upward although the change is greatest in activity 2. In other words, as would be expected in a closed economic system, any change in the demand for one agricultural activity will have implications for the demand levels of other agricultural activities because the well-known income and substitution effects come into play.

In scenario 3, the shift upward in the own-market coefficient of crop 2 also increases the land area allocated to crop 2, while the land areas devoted to crop 1 and 3 are again reduced. Again prices are bid up for all three crops but the greatest price increase is evident in crop 2 itself. Changes in the cross-market coefficients can be studied in much the same way by using equations (9a), (9b), or (9c).

Obviously the production-oriented model of von Thnen is sadly lacking in several respects. While the traditional model has a clear descriptive merit, the numerical analysis of this section of the paper makes it very clear that this traditional model, which only addresses production or supply in the various agricultural markets, is simply not very useful for making comparative-static predictions.

5. Agricultural Land Use Under Environmental Uncertainty

Since Davenport (1960), Gould (1963), and Wolpert (1964) geographers has shown some interest in studying agricultural activity in the face of environmental uncertainty. Webber (1972) indicated that yearly variations in yields (outputs) and instability in prices are major components of uncertainty in agriculture. Besides those factors, government programs and human management can also be included as sources of uncertainty. With regard to land use under such uncertainty, Terferliller and Hildreth (1961) have studied farmers decision making in the U.S. Great Plains and concluded that farmers expectations regarding annual rainfall is very close to rainfall levels that are experienced. Furthermore, they have found that

> "Farm sizes in the study area had increased substantially (over 60 percent) from 1947 to 1957. However, the size of own and rented farms remained almost constant during the 5-year drought period. These result suggests that a run of 'bad' years curtailed the acquisition of more land".

In addition, a recent report by Kenyon and Beckman (1996) regarding the interrelationships of price, weather, and land use is also notable; they have claimed that

> "Once every few years, supply and demand conditions for soybeans are such that prices reach high levels. These high prices are usually caused by reduced supply from poor yields during the summer but have also been caused by excessive rainfall.... When prices reach high levels in the first (current) year, two things generally happen in the following years. First, the high prices in year one lead producers to

expand acreage in year two. Second, the high prices in year one have a tendency to reduce demand for feed because of fewer numbers of livestock and poultry on feed".

In this section of the paper environmental uncertainty (specifically, climate variability) is examined in both von Thünen's production-oriented model and closed model. A maximum expected-return model, based on the idea of Cromley (1982), is developed to facilitate the analysis. However, at this time attention is not given to how annual fluctuations in yields might affect farmers' behavior.

Cromley pointed out that farmers maximize their long-run returns to land by estimating the highest expected rents at each distance k from the market, based on the production-oriented model. The expected returns depend upon the magnitudes of the different environmental-state probabilities and the associated yields for the crop in these environmental states. It should be pointed out that this approach is different from both the gambler-type and subsistence approaches to farming. In the gambler-type approach farmers entertain completely risky behavior and assume that annual environmental conditions will be most beneficial: they allocate their land to different crops assuming that a "best-case scenario" will occur each year. On the other hand, in the subsistence approach farmers fear a "worst-case scenario" every year and allocate their land uses accordingly. These two polar types of far[illegible] behavior reflect optimistic and pessimistic [illegible]res, [illegible] and neither is realistic for understanding long-run land-use allocations in capitalist economies.

To consider the more realistic expected-return approach, first assume that there are $j = 2$ environmental states, which can be simply called wet years and dry years. The yield E_{ij} for crop i varies with the environmental state but other parameters (price p_i, the non-land production costs a_i, and the transportation rate f_i) are assumed to remain constant regardless of climatic conditions in the production-oriented model. These environmental states could be numerous but only two states are used in this paper.

Given these assumptions, three expected-return bid-rent functions, combining the two environmental states, can be constructed as follows:

$$ER_1(k) = \phi[E_{11}(p_1 - a_1 - f_1 k)] + (1-\phi)[E_{12}(p_1 - a_1 - f_1 k)] \quad (11a)$$

$$ER_2(k) = \phi[E_{21}(p_2 - a_2 - f_2 k)] + (1-\phi)[E_{22}(p_2 - a_2 - f_2 k)] \quad (11b)$$

$$ER_3(k) = \phi[E_{31}(p_3 - a_3 - f_3 k)] + (1-\phi)[E_{32}(p_3 - a_3 - f_3 k)] \quad (11c)$$

where $0 \leq \phi$ 1 and

ϕ = the probability of environmental state 1(i.e., wet)

$(1-\phi)$ = the probability of environmental state 2(i.e., dry)

E_{11}, E_{12} = the yield of crop 1 in environmental states 1(wet), and 2(dry)

E_{21}, E_{22} = the yield of crop 2 in environmental states 1(wet), and 2(dry)

E_{31}, E_{32} = the yield of crop 3 in environmental states 1(wet), and 2(dry)

It is then an easy matter to estimate the expected yield E_1^*, E_2^*, and E_3^* for each of these three crops in any given year:

$$E_1^* = \phi E_{11} + (1-\phi)E_{12} \quad (12a)$$

$$E_2^* = \phi E_{21} + (1-\phi)E_{22} \quad (12b)$$

$$E_3^* = \phi E_{31} + (1-\phi)E_{32} \quad (12c)$$

Now the indifference points k_{12}, k_{23} and the extensive margin $k_{3,\max}$ are directly obtained from equations (11a), (11b), and (11c), as was done earlier in the paper for the situation of environmental certainty:

$$k_{12} = \{[E_{12} + \phi(E_{11} - E_{12})](p_1 - a_1) - [E_{22} + \phi(E_{21} - E_{22})](p_2 - a_2)\} / \{[E_{12} + \phi(E_{11} - E_{12})]f_1 - [E_{22} + \phi(E_{21} - E_{22})]f_2\} \quad (13a)$$

$$k_{23} = \{[E_{22} + \phi(E_{21} - E_{22})](p_2 - a_2) - [E_{32} + \phi(E_{31} - E_{32})](p_3 - a_3)\} / \{[E_{22} + \phi(E_{21} - E_{22})]f_2 - [E_{32} + \phi(E_{31} - E_{32})]f_3\} \quad (13b)$$

$$k_{3,\max} = (p_3 - a_3) / f_3 \quad (13c)$$

As a result, the land area for each crop, and the resulting output of each crop, can also be solved for the case of two-state environmental uncertainty. The land area devoted to each crop is simply computed by using equations (4a), (4b), and (4c), while the outputs Q_1, Q_2, and Q_3 are obtained by substituting E_1* for E_1, E_2* for E_2, and E_3* for E_3 and then applying equations (5a), (5b), and (5c). Note at the outset that the indifference points k_{12} and k_{23} are also a function of the probability of each environmental state.

1) Production-Oriented Model

The input data in Table 7 are now used to study land use allocations in the production-oriented model. Note that the highest yields of crops 2 and 3 are obtained during dry years while a wet year decreases the respective yields of these two crops. On the other hand, crop 1 has its highest yield in a wet environment and its lowest yield in a dry environment.

Substituting the data of the Table 7 into the above equations, the rent gradients of the expected-return model can be calculated. Note first, for crop 1, that the two extreme weather conditions, $\phi = 1$ and 0, form much different expected-return bid-rent functions. These two bid-rent functions are $ER_1(k) = 55 - 4k$ and $27.5 - 2k$, respectively. For crops 2 and 3, extreme weather conditions are again represented by $\phi = 1$ and $\phi = 0$: here the rent gradients are $ER_2(k) = 20 - 0.5k$ and $36 - 0.9k$ for crop 2, and $ER_2(k) = 7.5 - 0.05k$ and $45 - 0.3k$ for crop 3. In the analysis of this paper, all expected-return rent gradients are located between these two extreme values. For example, in case of $\phi = 0.8$, the rent gradients for $ER_1(k)$, $ER_2(k)$, and $ER_3(k)$ are $49.5 - 3.6k$, $23.2 - 0.58k$, and $15 - 0.1k$, respectively. As in the environmentally certain versions of the von Thnen model, these expected-return bid-rent functions serve to indicate which crop will be grown at any given distance from the market town. The indifference points and the extensive margin can be simply obtained by setting $ER_1(k) = ER_2(k)$, $ER_2(k)= ER_3(k)$, and $ER_3(k)= 0$.

Table 8 shows various solutions for the production-oriented model, where the probabilities $\phi = 1.0$, 0.9, 0.8, and 0.7, denoting generally wet conditions, are used in equations (11a), (11b), and (11c). The outer cultivation radius of crop 1 moves inward from $k_{12} = 10$, 9.402, 8.709, 7.896, and then 6.929 distance units as the probability of a wet year declines. Likewise, these changes shift the outer cultivation radius of crop 2 from $k_{23} = 27.778$, 22.258, 15.083, 12.222, and then 7.647. It is worthwhile to note that the maximum radius of cultivation, for crop 3, is always maintained at $k_{3,max} = 150$ despite these changes in environmental probabilities.

Land areas and outputs of crops 1 and 2 are reduced, as environmental conditions become increasingly less wet. The land devoted to crop 2, and its related output, are especially reduced from their high levels during wet years as dryer conditions become increasingly more probable.

Table 7. Input Data in Expected-Return Model

	Crop 1	Crop 2	Crop 3
Yield:wet (E_{i1})	20	10	5
Yield:dry (E_{i2})	10	18	30
Price (p_i)	6	4	3
Production Cost (a_i)	3.25	2.00	1.50
TransportationRate (f_i)	0.20	0.05	0.01

Table 8. The Effect of Changes in Environmental State (ϕ = 1.0, 0.9, 0.8, 0.7, 0.6)

Probability (ϕ)	Q_1	Q_2	Q_3	k_{12}(Area 1)	k_{23}(Area 2)	$k_{3,max}$(Area 3)
1.0	2,000.0π	6,716.0π	108,642.0π	10.000(100π)	27.778(671.6π)	150(21,728.4π)
0.9	1,679.5π	4,395.9π	165,034.3π	9.402(88.4π)	22.258(407.0π)	150(22,004.6π)
0.8	1,365.1π	2,505.6π	222,081.6π	8.709(75.8π)	15.083(216.0π)	150(22,208.2π)
0.7	1,059.8π	1,079.3π	279,382.7π	7.896(62.3π)	12.222(87.0π)	150(22,350.6π)
0.6	768.2π	138.1π	336,622.8π	6.929(48.0π)	7.647(10.5π)	150(22,441.5π)

On the contrary, the land devoted to crop 3 expands further inward, and the output of crop 3 steadily increases, with these same probabilistic shifts in environmental conditions.

If the probability of the wet environmental state is 0.5, the probabilistic bid-rent functions are $ER_1(k) = 41.25 - 3k$, $ER_2(k) = 28 - 0.7k$, and $ER_3(k) = 26.25 - 0.175k$. The indifference points are $k_{12} = 5.761$ and $k_{23} = 3.333$ in the numerical computation. This situation arises due to the competitiveness of crop 3 in dry climatic conditions, and a new indifference point ($k_{13} = 5.310$) between crops 1 and 3 is obtained inside the indifference point between crops 1 and 2. This change in the rent gradients means that just two active crop activities in land use among the possible three crop activities, are actually undertaken. The new land use pattern shows only two crops, 1 and 3. As the values of ϕ continue to decline to 0.5, 0.4, and 0.3, the outputs and land areas of these two crops are shown in Table 9.

The table shows that crop 3, which prevails in dry conditions, becomes increasingly dominant over crop 1 as the result of competition. If the probability ϕ moves even lower to a value of 0.269, another transition occurs where the rent gradient is everywhere higher than the rent gradient of crop 1. Now only one activity is undertaken and all land is devoted to crop 3.

Although the analysis from the expected-return model certainly depends on the input data, the model demonstrates how varying climatic conditions can influence farmers long-run decisions and elicit significant changes in the land use patterns on the agricultural landscape. It is worth stressing, too, that farmers certainly cannot guarantee these returns in any given year. In some years, their actual rents will exceed expected values while in other years their actual rents will fall short of expected values. Instead, these returns to land represent what they can expect to receive under uncertainty, on the average, over a period of many years. This model makes a lot of sense because farmers are assumed to be aware of their immediate environmental conditions and to adapt their farming strategies accordingly.

2) Closed Model

While the expected-return model outlined above certainly helps to incorporate further realism into von Thnen analysis, the analysis still suffers because the model does not close all of the various agricultural markets for market demand. As was the case for environmental certainty earlier in the paper, demand curves must be introduced for each of the three activities competing for scarce land around the market town. Table 10 shows that the parametric values used for the simulations of this section of the paper. Once again the linear curves of equations (9a), (9b), and (9c) are employed.

Equilibrium solution for the closed model are

Table 9. The Effect of Changes in Environmental State ($\phi = 0.5, 0.4, 0.3$)

Probability (ϕ)	Q_1	Q_3	k_{13} (Area 1)	$k_{3,max}$ (Area 3)
0.5	422.9π	$393{,}256.6\pi$	$5.310(28.2\pi)$	$150(22{,}471.8\pi)$
0.4	149.6π	$449{,}786.2\pi$	$3.269(10.7\pi)$	$150(22{,}489.3\pi)$
0.3	9.2π	$506{,}234.1\pi$	$0.842(0.7\pi)$	$150(22{,}499.3\pi)$

Table 10. Exogenous Intercepts and Coefficients in Expected -Return Model

	Intercepts(δ_i)	Coefficients(λ_{ij})		
Crop 1	10	$1/350\pi$	$1/70{,}000\pi$	$1/500{,}000\pi$
Crop 2	7	$1/350{,}000\pi$	$1/2{,}400\pi$	$1/1{,}000{,}000\pi$
Crop 3	5	$1/500{,}000\pi$	$1/800{,}000\pi$	$1/58{,}600\pi$

also specified by first solving for E_1*, E_2*, and E_3* per equations (12a), (12b), and (12c), and then by substituting E_1* for E_1, E_2* for E_2, and E_3* for E_3 in equations (10a), (10b), and (10c). This operation leads to iterative solutions for k_{12}, k_{23}, and $k_{3,max}$ as was shown earlier for the case of environmental certainty. Prices p_1, p_2, and p_3, land areas A_1, A_2, and A_3, and outputs Q_1, Q_2, and Q_3 are then computed as before.

The simulated results shown in Table 11 indicate that when the demand data from Table 10 are used, all three agricultural activities persist on the landscape irrespective of the value of the environmental-state probability parameter. This stands in marked contrast to the production-oriented model, where three different types of agricultural landscapes were identified as this parameter was shifted from $\phi = 1$ (extreme wet conditions) to $\phi = 0$ (extreme dry conditions).

Furthermore, this table shows price variation, and the consequent changes in land areas and outputs, for each crop in response to various climatic conditions, as represented by the following parameter values: ϕ = 1.0, 0.7, 0.5, 0.3, 0.0. Based on these adopted input data, the lowest price for crop 1, p_1 = 5.7112, occurs when conditions are maximally wet and $\phi = 1$. As the probability ϕ is lowered, the price for crop 1 is continuously increased until it reaches its highest price, p_1 = 7.6949, when $\phi = 0$ and extreme dry conditions persist. As would be expected, the price movement for crop 3 is entirely opposite to the price movement of crop 1. That is, the highest price occurs when $\phi = 1$ and the lowest when $\phi = 0$. However, the price movement of crop 2 is not straightforward to understand as the variation does not show a monotonic pattern with changes in the environmental state. Among the five different environmental states the highest price, p_2 = 4.0824, is reached when ϕ = 0.7 while lower prices are found in both the more extreme environmental conditions. Moreover, the price variation of crop 2 is very small, compared to the price variation of crops 1 and 3. This would seem to have implications of importance, as farmers seeking a maximum expected return should expect a stable price for crop 2 regardless of climatic conditions. This stands in marked contrast to the production-oriented model where crop 2 is eventually squeezed out of the market as environmental conditions become increasingly dry. In the production-oriented model total land area is hardly changed in response to environmental variability (see Tables 8 and 9). However, in the closed model total land area is very responsive to changes in the environmental states. Under extremely wet conditions agriculture is very widespread (23,629.54π units) but under extremely dry conditions agriculture is severely contracted (5,780.3π units). This indicates that it is very important to include market demand in a von Thnen model that addresses environmental uncertainty.

Table 11. The Effect of Changes in Environmental State in the Closed Model

	Environmental Probability ϕ				
	1.0	0.7	0.5	0.3	0.0
p_1	5.7112	6.1515	6.4882	6.8889	7.6949
p_2	4.0083	4.0824	4.0680	4.0365	3.9727
p_3	3.0372	2.5891	2.4513	2.3579	2.2603
k_{12}	8.333	8.456	8.532	8.547	8.135
k_{23}	27.556	24.665	23.446	22.469	21.176
$k_{3,max}$	153.724	108.917	95.134	85.798	76.024
A_1	69.3π	71.5π	72.8π	72.9π	66.0π
A_2	689.6π	536.8π	476.6π	431.8π	382.1π
A_3	22,870.6π	11,252.1π	8,499.4π	6,854.5π	5,332.2π
Q_1	1,387π	1,215π	1,092π	947π	660π
Q_2	6,896π	6,656π	6,672π	6,736π	6,877π
Q_3	114,353π	140,651π	148,740π	154,226π	159,966π

6. Summary and Conclusion

This paper has provided a severe critique of the traditional, production-oriented model of von Thnen analysis. Linear demand curves were introduced and the traditional model was subsequently closed for all agricultural activities. This was accomplished by setting quantity demanded equal to quantity supplied in all agricultural markets. All of the analysis used three agricultural activities in the familiar situation where a dimensionless town provides markets for surrounding agricultural activities on an isotropic plain.

Comparative static analysis showed that the production-oriented model tends to exaggerate price, output, and land area shifts when compared to the closed model. The traditional model is useful for descriptive purposes but seems very weak for predictive purposes.

The analysis in the first part of the paper was carried out under the usual conditions of environmental certainty. In the second half of the paper, environmental uncertainty was examined. A maximum expected-return version of both the production-oriented and closed models was developed. In these cases rent gradients were based on the long-run climatic expectations of farmers. The solutions to both models showed that the closed model had much more land use stability than the traditional model. In other words, when environmental conditions shifted from wet to dry in the closed model, activities were not squeezed out of the market as they would be in the production-oriented model. Prices also proved to be much more stable in the closed model.

This paper is a preliminary attempt to introduce environmental uncertainty into the von Thnen framework. The maximum expected-return approach is one of several approaches to the problem that could be formulated. As the paper briefly suggests, gambler-type and subsistence-type strategies might also be entertained. In fact, in the real world there could be a mixture of such behaviors in an agricultural region. The problem, then, would be to aggregate together those farmers sharing the same strategies and to build this into a more complicated, closed von Thünen model. Prices, outputs, and land area, would then shift as farmers changed their strategies from one type to another.

References

Cromley, R.G., 1982, The von Thnen model and environmental uncertainty, *Annal of the Association of American Geographers*, 72, 404-10.

Dunn, Jr., E.S.,1954, *The location of agricultural production*, Gainesville: University Florida Press.

Found, W. C., 1971, *A theoretical approach to tural land-land use patterns*, London: Edward Arnold.

Gould, P.R., 1963, Man against his environment: a game theoretic framework, *Annals of the Association of American Geographers*, 53, 290-97.

Harvey, D. W., 1963, Theoretical concepts and the anlysis of agricultural land-use patterns in geography, *Annals of the Association of American Geographers*, 56, 290-97.

Hoover, E. M., 1948, *The location of Economic Activity*, New York: McGraw-Hill.

Isard, W., 1956, *Location and space-economy*, Cambridge, MIT Press.

Jones, A., McGuire, W., and Witte, A., 1978, A reexamination of some aspects of von Thnens model of spatial location, *Journal of Regional Science*, 18, 1-15.

Jones, D. W., 1978, Rent in an Equilibrium model of land use, *Annals of the Association of American Geographers*, 68, 205-213.

Kellerman, A., 1989a, Agricultural location theory 1: basic models, *Environment and Planning A*, 21, 1381-96.

Kellerman, A., 1989b, Agricultural location theory 2: relaxation of assumptions and applications, *Environment and Planning A*, 21, 1427-46.

Kenyon, D., and Beckman, C., 1996, *Multiple year pricing strategies for soybeans and cottons*,Virginia Cooperative Extension; Knowledge for the Common Wealth.

Mulligan, G. F.,1996, *Some implications of* *behaviour in agricultural markets*, Discussion Paper 96-6, Department of Geography and regional Development, The University of Arizona.

Nerlove, M. L, and Sadka, E., 1991, Von Thnens model of the dual economy, *Journal of Economics*, 54, 97-123.

Norton, W., and Conkling, E., 1974, Land use theory and the pioneering economy, *Geografiska Annaler*, 56, 44-56.

Peet, R., 1969, The spatial expansion of commercial agriculture in the nineteenth century: a von Th¨nen interpretation, *Economic Geography*, 45, 283-301.

Samuelson, P., 1983, Thünen at two hundred, *Journal of Economic Literature*, 21, 1468-88

Tefertiller, K., and Hildreth, R., 1961, Importance of weather variability in management decision, *Journal of Farm Economics*, 43, 1163-69.

Webber, M., 1972, *Impact of uncertainty on location*, Cambridge: MIT Press.

Wolpert, J., 1964, The decision process in spatial context, *Annals of the Association of American Geographers*, 54, 537-58.

불확실한 환경조건에서 농업시장의 행동: 튀넨 모델을 배경으로 한 이론적 접근

이상율*, Gordon F. Mulligan**

본 연구는 기존의 튀넨 모형(또는, 생산지향 모형)의 결함을 보완하기 위한 Closed 모형의 개발과 이의 검증을 중심으로 한 연구이다. 생산지향모형의 가장 큰 결함은 시장기능을 도외시한 점이라고 할 수 있는데, 특히 시장가격의 결정 구조가 전혀 고려되지 않은 점이다. 이러한 문제를 바탕으로 생산지향 모형에서 도출된 농산물의 공급측 가격과 일반적인 수요측면에서 도출된 가격, 이 양자의 상호결합에 의해 Closed 모형이 제시되었다. 이 모형은 시뮬레이션(simulation)에 의해 검정되고 생산지향 모형과 비교되었다. 그 결과는 첫째, 생산지향 모형에서 경작지 면적은 운송비 감소와 생산비의 절감에 Closed 모형의 결과에 비해 과도하게 증가하는 예측이 이루어진다. 둘째, Closed 모형에서는 농산물 농산물 가격이 사장기능에 의해 조절되며 변화한다는 점이 파악된다. 셋째, 특정작물의 단위당 생산량의 증가는 생산지향 모형에서는 그 작물의 공간적인 확대로 연결되고 시장가격은 불변인데 비해 Closed 모형에서는 반드시 그러한 공간확대로 이어지지는 않고, 수요가 일정한 상태일 때는 오히려 경작지 면적이 줄 수 있다고 예상된다.

이와 같은 성격을 갖고 있는 Closed 모형이, 불확실한 환경조건에서 농작물 상호간의 경쟁하에 경작지면적, 작물의 총생산량, 및 시장가격의 결정을 이해하기위해서 응용되었다. 본 연구에서는 우선 생산지향 모형을 바탕으로, 다양한 기후변화에 따른 토지이용의 변화를 경쟁입찰지대(bid-rent) 수식에 의해 파악해보았다. 그 결과는 어떤 특정한 기후에서 다른 작물보다 열등인 작물은 쉽게 공간에서 배제되는점에 비해, Closed 모형에서는 비록 기후조건이 나쁜 환경에 처한 작물이라도 그 작물에 대한 수요가 있을 경우에는 계속적으로 경작이 된다는 결과를 보인다. 반면에 기후조건이 유리한 작물은 생산량의 증대로 시장가격은 하락되고, 일정한 수요상태에서는 경작지면적의 감소로 이어지는 결과가 예측된다.

주요어: 튀넨 모형, Closed 모형, 시장가격, 토지이용, 불확실한 환경

* 아리조나 주립대학 지리 및 지역개발학과 박사과정
** 아리조나 주립대학 지리 및 지역개발학과 교수