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Theoretical Analysis of Urban Land Use Change by Information Provision for Nankai Trough Huge Earthquake in Japan

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1. Introduction

Various disaster measures have domestically been done from both hard aspect and soft side since Great East Japan Earthquake occurred. The tide embankments were collapsed by tsunami when Great East Japan Earthquake occurred, and the country and the local government started to pay attention to the hazard map as an evacuation measure that secures the life in top priority. Information on disaster risk relates the location of land and the level of damage when a big earthquake occurs. The hazard map is one of such information sources. Moreover, at Great East Japan Earthquake, a lot of small and medium-sized firms lost human resources and equipment, hence those firms must be closed down. Considering this business operating situation, there is a movement where the earthquake damage on firms is managed to be small by protecting firms' equipments by making and operating a BCP (business continuity planning). The Headquarter of Earthquake Research Promotion in Ministry of Education, Culture, Sports, Science and Technology in Japan estimates the occurrence probability of Nankai (Southern Sea in Japan) Trough Huge Earthquake within 30 years from now as 70%. Thus such a soft side measure for a huge earthquake should immediately be implemented, and the measurement of effects of earthquake information provision is expected to be a backup for soft measures.

The theoretical studies concerning the effects of provision of earthquake information are extremely few (e.g. Yamaguchi et al.), and simulation analyses of those effects on an actual city is also extremely few. Therefore this article aims to investigate the household location choice behavior affected by provision of earthquake damage information taking Toyohashi City in Japan as a study region which is expected to receive a significant damage by Nankai Trough Huge Earthquake.

This study employs an analytic urban economics approach, assuming that Toyohashi City takes a linear shape and there are two districts where the vulnerabilities to an earthquake in the two districts are different. That is, Toyohashi City is divided into two districts, one is safe for an earthquake while another one is risky for an earthquake. And then this study theoretically considers how the land rent and the land use pattern of these two districts will be changed by provision of earthquake damage information and by a change in household subjective trust in earthquake information.

2. Assumptions in the Model

This study assumes a closed city model and the number of the city population is N which is fixed before and after an earthquake. Also absentee land ownership is assumed. Each household obtains the same and fixed income and has the same preference. Every household commutes to the CBD and the commuting cost depends on only the distance r from the CBD. The commuting cost per distance is invariant in the normal state and even after an earthquake. Toyohashi City consists of two districts, namely the safe district A and the risky district B. The shape of Toyohashi City is assumed to be linear with width of h (see Figure 1). This assumption asserts that the vulnerability of the land in the city differs at different location and the living condition for each household differs after an earthquake. When the city is in the normal state, each household can obtain the same living condition a_0 in the both districts, while when an earthquake occurs, the living condition for each household in district B falls to a_1 keeping the living condition in district A at a_0 . Although some parts of this study depend on the achievements by Yamaguchi et. al. 1) and 2), the assumption in which the safe district is located across the CBD is one of originari-

ties taking account of Toyohashi's real geographical condition.

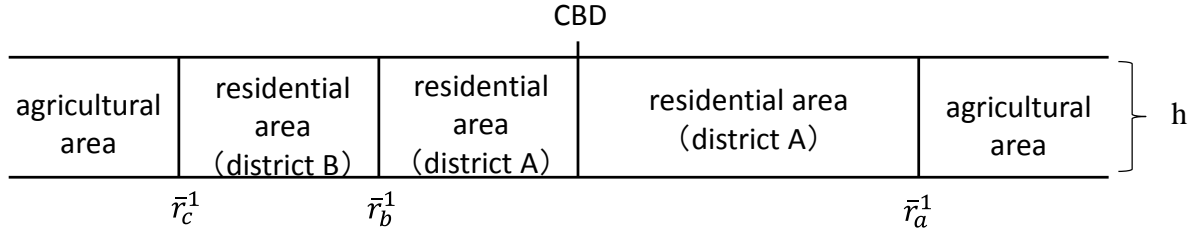


Figure 1 Urban Configuration of the Study Area

3. The Case without Household Subjective Trust in Earthquake Information

3.1 Household Behavior

(1) Household Expected Utility

The location of each household is indicated by $\delta = A$ or B , which shows district A or B, and the distance from the CBD by r . Each household is assumed to consume commodities and to choose a location so as to maximize its utility function. In normal state, each household can obtain the utility level of $u(s, z, a_0) > 0$ consuming land s and composite good z with the living condition a_0 . However once a household suffer the damage from an earthquake, the living condition gets down to a_1 resulting in a decreased utility $u(s, z, a_1)$. Here this study assumes a huge earthquake like Nankai Trough Huge Earthquake, hence the utility function of each household becomes 0, i.e. $u(s, z, a_1) = 0$ even given any consumption opportunity.

Moreover we denote a probability of earthquake occurrence by $p(0 \leq p \leq 1)$, and assume that every household knows this probability under perfect information. Then the household expected utility function $EU_\delta^1(s, z, r)$ at the location (δ, r) with land and commodity consumptions s and z can be written as follows:

$$EU_A^1(s, z, r) = u(s, z, a_0) \quad (1)$$

$$EU_B^1(s, z, r) = (1 - p)u(s, z, a_0) + pu(s, z, a_1) \quad (2)$$

However if information of earthquake risk is not provided, any household can not know a change of the living condition by earthquake occurrence before an earthquake. Let $\varepsilon(0 < \varepsilon \leq 1)$ be a conditional subjective probability of the occurrence of living condition a_0 that a representative household has after an earthquake. Hence the household expected utility without any information can be given as follows:

$$\begin{aligned} EU_A^0(s, z, r) &= EU_B^0(s, z, r) = (1 - p)u(s, z, a_0) + p\varepsilon u(s, z, a_0) \\ &= (1 - p + \varepsilon p)u(s, z, a_0) \end{aligned} \quad (3)$$

(2) Household Behavior

Let i denote the information state ($i = 1$: perfect information and $i = 0$: null information), y denote the household nominal income and t denote the transportation cost in unit distance. Then the household behavior can be specified as follows:

$$\max_{s, z} EU_\delta^i(s, z, r) \quad (4)$$

$$\text{subject to } R_\delta^i(r)s + z + tr = y \quad (5)$$

The household demand functions for land and composite good at the household living place (δ, r) are given by the solution of the following optimization problem.

$$V_\delta^i(R_\delta^i(r), y - tr) = \{\max_{s, z} EU_\delta^i(s, z, r) | R_\delta^i(r)s + z + tr = y\} \quad (6)$$

The first order necessary conditions for the problem (4) and (5) is expressed by the following equations with the Lagrangian multiplier λ_δ^i .

$$\begin{cases} \partial EU_\delta^i / \partial s = \lambda_\delta^i R_\delta^i(r) \\ \partial EU_\delta^i / \partial z = \lambda_\delta^i \\ R_\delta^i(r)s + z = y - tr \end{cases} \quad (7)$$

Solving the system of equations (7), demand functions for land and composite consumption at the household location (r, δ) with the information state i are written as follows:

$$s_\delta^i = s(R_\delta^i(r), y - tr) \quad (8)$$

$$z_\delta^i = z(R_\delta^i(r), y - tr) \quad (9)$$

The household subjective utility level is given by the indirect utility level $v_\delta^i(R_\delta^i(r), y - tr)$ and the household residential location choice is obtained by the solution $(r_\delta^{i*}, \delta^*)$ of the following optimization problem;

$$\max_{\delta, r} \{V_\delta^i(R_\delta^i(r), y - tr)\}. \quad (10)$$

3.2 Equilibrium Land Use

The household bid rent $\Psi_\delta^i(r, u; p)$, that is, the maximum land rent that a household residing at location r can pay keeping its utility level u is defined as follows:

$$\Psi_\delta^i(r, u; p) = \max_{z, s} \left\{ \frac{y - tr - z}{s} \mid EU_\delta^i(s, z, r) = u \right\} \quad (11)$$

When we assume that every point in the city is used by a rent bidder who pay the highest rent among other households and the agricultural land rent is denoted by R_A , then the market rent function $R_\delta^i(r)$ is denoted as follows:

$$R_\delta^i(r) = \max\{\Psi_\delta^i(r, u^i; p), R_A\} \quad (12)$$

Then the equilibrium household utility level with the earthquake occurrence probability p satisfying $\Psi_\delta^i(r, u; p) \geq R_A$ is written as follows by using the indirect utility function $v(R_\delta^i(r), y - tr)$.

$$u^1 = u(s_A^1, z_A^1, a_0) = v(\Psi_A^1(r, u^1; p), y - tr) \quad (13)$$

$$= u(s_B^1, z_B^1, a_0) = (1 - p)v(\Psi_B^1(r, u^1; p), y - tr) \quad (14)$$

$$u^0 = u(s_\delta^0, z_\delta^0, a_0) = (1 - p + \varepsilon p)v(\Psi_\delta^0(r, u^0; p), y - tr) \quad (15)$$

The equilibrium bid rent functions are obtained solving equations (13), (14) and (15) with respect to $\Psi_\delta^i(r, u^i; p)$ with Solow's bid rent function $\psi(u, y - tr)$.

$$\Psi_A^1(r, u^1; p) = \psi(u^1, y - tr) \quad (16)$$

$$\Psi_B^1(r, u^1; p) = \psi\left(\frac{u^1}{1-p}, y - tr\right) \quad (17)$$

$$\Psi_\delta^0(r, u^0; p) = \psi\left(\frac{u^0}{1-p+\varepsilon p}, y - tr\right) \equiv \Psi^0(r, u^0; p) \quad (18)$$

Denoting a district, information state and the distance to the city boundary by δ , i and \bar{r}_δ^i , respectively, then the following equations are obtained.

$$\Psi_A^1(\bar{r}_a^1, u^1; p) = \Psi_B^1(\bar{r}_c^1, u^1; p) = R_A \quad (19)$$

$$\Psi^0(\bar{r}_\delta^0, u^1; p) = R_A \quad (20)$$

where

\bar{r}_a^1 : distance from the CBD to the boundary between district A and the agricultural area

\bar{r}_b^1 : distance from the CBD to the boundary between districts A and B

\bar{r}_c^1 : distance from the CBD to the boundary between district B and the agricultural area

From equation (20), $\bar{r}_a^0 = \bar{r}_c^0 \equiv \bar{r}^0$ is realized for \bar{r}_δ^i such that $\bar{r}_\delta^i \geq 0$. Now the number of households n_δ^i residing in the city with unit sistance and width h is written as follows:

$$n_\delta^i(R_\delta^i(r), y - tr) = \frac{h}{s(R_\delta^i(r), y - tr)} \quad (21)$$

Hence the total number of households in the city at the equilibrium land use pattern is expressed as follows:

$$N = \begin{cases} \int_0^{\bar{r}_a^1} \left\{ \frac{h}{s(\Psi_A^1(r, u^1; p), y - tr)} \right\} dr + \int_0^{\bar{r}_b^1} \left\{ \frac{h}{s(\Psi_A^1(r, u^1; p), y - tr)} \right\} dr + \int_{\bar{r}_b^1}^{\bar{r}_c^1} \left\{ \frac{h}{s(\Psi_B^1(r, u^1; p), y - tr)} \right\} dr \\ 2 \int_0^{\bar{r}^0} \left\{ \frac{h}{s(\Psi_\delta^0(r, u^0; p), y - tr)} \right\} dr = \int_0^{\bar{r}^0} \left\{ \frac{h}{s(\Psi_A^0(r, u^0; p), y - tr)} \right\} dr + \int_0^{\bar{r}^0} \left\{ \frac{h}{s(\Psi_B^0(r, u^0; p), y - tr)} \right\} dr \end{cases} \quad (22)$$

Solving equations (13), (14), (15), (19), (20) and (22), we endogenously obtain the equilibrium utility level u^i , the distance from the CBD to the city boundary \bar{r}_δ^i and the equilibrium bid rent function $\Psi_\delta^i(r, u^i; p)$.

3.3 Comparative Static Analysis for the Equilibrium Location

In this section we consider the economic impact on the land market induced by provision of information of the earthquake risk in the normal state. In land use equilibrium, the equilibrium utility level takes the same value for different location. Hence denoting the household real income by $y - tr = Y$, the differentiation of equation (6) with respect to r yields;

$$\frac{\partial V_\delta^i(\Psi_\delta^i, Y)}{\partial R_\delta^i} \frac{\partial \Psi_\delta^i(r, u^i; p)}{\partial r} - \frac{\partial V_\delta^i(\Psi_\delta^i, Y)}{\partial Y} t = 0 \quad (23)$$

Thus the following equation is obtained.

$$\frac{\partial V_\delta^i(\Psi_\delta^i, Y) / \partial R_\delta^i}{\partial V_\delta^i(\Psi_\delta^i, Y) / \partial Y} \frac{\partial \Psi_\delta^i(r, u^i; p)}{\partial r} = t \quad (24)$$

From Roy's identity, we have the following equation.

$$\frac{\partial V_\delta^i(\Psi_\delta^i, Y) / \partial R_\delta^i}{\partial V_\delta^i(\Psi_\delta^i, Y) / \partial Y} = s(\Psi_\delta^i(r, u^i; p), Y) \quad (25)$$

Equation (24) together with equation (25) yields equation (26).

$$\frac{1}{s(\Psi_\delta^i(r, u^i; p), Y)} = - \frac{\partial \Psi_\delta^i(r, u^i; p)}{\partial r} \frac{1}{t} \quad (26)$$

Substituting equation (26) for equation (22), the total number of households in the city can be expressed as follows:

$$N = \begin{cases} \frac{h}{t} \{ 2\Psi_A^1(0, u^1; p) + \Psi_B^1(\bar{r}_b^1, u^1; p) - \Psi_A^1(\bar{r}_b^1, u^1; p) - 2R_A \} \\ \frac{2h}{t} \{ \Psi_\delta^0(0, u^0; p) - R_A \} = \frac{h}{t} \{ \Psi_A^0(0, u^0; p) + \Psi_B^0(0, u^0; p) - 2R_A \} \end{cases} \quad (27)$$

Since we assume a closed city, the differentiation of equation (27) with respect to the earthquake occurrence probability p leads to equation (28) when information is perfectly provided ($i = 1$).

$$\begin{aligned} \frac{dN}{dp} &= \frac{h}{t} \left\{ 2 \frac{d\Psi_A^1(0, u^1; p)}{dp} + \frac{d\Psi_B^1(\bar{r}_b^1, u^1; p)}{dp} - \frac{d\Psi_A^1(\bar{r}_b^1, u^1; p)}{dp} \right\} \\ &= \frac{h}{t} \left\{ 2 \frac{\partial \psi(u^1, y)}{\partial u} \frac{\partial u^1}{\partial p} + \frac{\partial \psi\left(\frac{u^1}{1-p}, y - t\bar{r}_b^1\right)}{\partial u} \frac{\partial u^1}{\partial p} \frac{(1-p) + u^1}{(1-p)^2} - \frac{\partial \psi(u^1, y - t\bar{r}_b^1)}{\partial u} \frac{\partial u^1}{\partial p} \right\} \\ &= \frac{h}{t} \left\{ \left(2 \frac{\partial \psi(u^1, y)}{\partial u} - \frac{\partial \psi(u^1, y - t\bar{r}_b^1)}{\partial u} \right) \frac{\partial u^1}{\partial p} + \frac{\partial \psi\left(\frac{u^1}{1-p}, y - t\bar{r}_b^1\right)}{\partial u} \frac{\partial u^1}{\partial p} \frac{(1-p) + u^1}{(1-p)^2} \right\} \equiv 0 \end{aligned} \quad (28)$$

Here we examine the sign of each term in equation (28) to investigate the impact on the bid rent corresponding to a change in the earthquake occurrence probability p .

From the property of a bid rent function, $\frac{\partial \psi(u, Y)}{\partial u} < 0$ holds. Hence we have;

$$\frac{\partial \psi(u^1, Y)}{\partial u}, \frac{\partial \psi\left(\frac{u^1}{1-p}, Y - t\bar{r}_B^1\right)}{\partial u} \text{ and } \frac{\partial \psi(u^1, Y - t\bar{r}_B^1)}{\partial u} < 0 \quad (29)$$

Moreover the bid rent function $\psi(u, Y)$ is a continuous and increasing function in the real income Y and a decreasing function in the utility level u . Therefore the following inequality holds.

$$\psi(u^1, Y) > \psi(u^1, Y - t\bar{r}_B^1) \quad (30)$$

Since $u > 0$ and $Y > 0$, the following inequality is also realized.

$$\frac{\partial \psi(u^1, Y)}{\partial u} < \frac{\partial \psi(u^1, Y - t\bar{r}_B^1)}{\partial u} < 0 \quad (31)$$

This inequality leads to;

$$2 \frac{\partial \psi(u^1, Y)}{\partial u} - \frac{\partial \psi(u^1, Y - t\bar{r}_B^1)}{\partial u} < 0 \quad (32)$$

Therefore when inequality (32) holds, two terms $\frac{\partial u^1}{\partial p}$ and $\frac{\frac{\partial u^1}{\partial p}(1-p) + u^1}{(1-p)^2}$ must have the different signs each other to realize equation (28) leading to the following inequality.

$$\left(\frac{\partial u^1}{\partial p}\right) \left(\frac{\frac{\partial u^1}{\partial p}(1-p) + u^1}{(1-p)^2}\right) < 0 \quad (33)$$

If $\frac{\partial u^1}{\partial p} > 0$ holds, this contradicts inequality (33) because of the assumption of $u^1 > 0$. Thus when the land market is in equilibrium, the following inequalities hold.

$$\frac{\partial u^1}{\partial p} < 0 \quad (34)$$

$$\frac{\frac{\partial u^1}{\partial p}(1-p) + u^1}{(1-p)^2} > 0 \quad (35)$$

From equations (16) and (34), the following inequality is obtained.

$$\frac{d\Psi_A^1(r, u^1; p)}{dp} = \frac{\partial \psi(u^1, Y)}{\partial u} \frac{\partial u^1}{\partial p} > 0 \quad (36)$$

From inequality (36), it can be said that the bid rent in district A increases as the earthquake occurrence probability p rises. Similarly formulae (17) and (34), we obtain the following inequality.

$$\begin{aligned} \frac{d\Psi_B^1(r, u^1; p)}{dp} &= \frac{\partial \psi\left(\frac{u^1}{(1-p)}, Y\right)}{\partial u} \frac{\partial\left(\frac{u^1}{(1-p)}\right)}{\partial p} \\ &= \frac{\partial \psi\left(\frac{u^1}{(1-p)}, Y\right)}{\partial u} \frac{\frac{\partial u^1}{\partial p}(1-p) + u^1}{(1-p)^2} < 0 \end{aligned} \quad (37)$$

From inequality (37), it can be concluded that the bid rent in district B decreases as the earthquake occurrence probability p increases. Next we turn to the case of null earthquake information ($i = 0$). Under this situation, the following equation is obtained.

$$\begin{aligned} \frac{dN}{dp} &= \frac{h}{t} \left\{ \frac{d\Psi_A^0(0, u^0; p)}{dp} + \frac{d\Psi_B^0(0, u^0; p)}{dp} \right\} \\ &= \frac{2h}{t} \left\{ \frac{\partial \psi\left(\frac{u^0}{(1-p+\varepsilon p)}, Y\right)}{\partial u} \frac{\frac{\partial u^0}{\partial p}(1-p+\varepsilon p) - u^0(-1+\varepsilon)}{(1-p+\varepsilon p)^2} \right\} \equiv 0 \end{aligned} \quad (38)$$

Thus for the equilibrium in the land market, the next equation is necessary.

$$\frac{\frac{\partial u^0}{\partial p}(1-p+\varepsilon p) - u^0(-1+\varepsilon)}{(1-p+\varepsilon p)^2} \equiv 0 \quad (39)$$

Since $(1 - p + \varepsilon p) > 0$, $u^0 > 0$ and $(-1 + \varepsilon) < 0$, we have;

$$\frac{\partial u^0}{\partial p} < 0 \quad (40)$$

Under inequality (40), the following equality holds from formulae (38) and (39).

$$\begin{aligned} \frac{d\Psi^0(r, u^0; p)}{dp} &= \frac{\partial \psi\left(\frac{u^0}{(1-p+\varepsilon p)}, Y\right)}{\partial u} \frac{\partial \left(\frac{u^0}{(1-p+\varepsilon p)}\right)}{\partial p} \\ &= \frac{\partial \psi\left(\frac{u^0}{(1-p+\varepsilon p)}, Y\right)}{\partial u} \frac{\frac{\partial u^0}{\partial p}(1-p+\varepsilon p) - u^0(-1+\varepsilon)}{(1-p+\varepsilon p)^2} \equiv 0 \end{aligned} \quad (41)$$

The number of households in the city is invariant with respect to the household subjective risk probability for an earthquake, so the following identity holds.

$$\begin{aligned} \frac{dN}{d\varepsilon} &= \frac{h}{t} \left\{ \frac{d\Psi_A^0(0, u^0; p)}{d\varepsilon} + \frac{d\Psi_B^0(0, u^0; p)}{d\varepsilon} \right\} \\ &= \frac{2h}{t} \left\{ \frac{\partial \psi\left(\frac{u^0}{(1-p+\varepsilon p)}, Y\right)}{\partial u} \frac{\frac{\partial u^0}{\partial \varepsilon}(1-p+\varepsilon p) - pu^0}{(1-p+\varepsilon p)^2} \right\} \equiv 0 \end{aligned} \quad (42)$$

To realize identity (42), the next equality is necessary.

$$\frac{\frac{\partial u^0}{\partial \varepsilon}(1-p+\varepsilon p) - pu^0}{(1-p+\varepsilon p)^2} \equiv 0 \quad (43)$$

Since $(1 - p + \varepsilon p) > 0$, $u^0 > 0$ and $p \geq 0$, then we have;

$$\frac{\partial u^0}{\partial \varepsilon} > 0 \quad (44)$$

When equations (41) and (42) hold, the next identity is also realized.

$$\begin{aligned} \frac{d\Psi^0(r, u^0; p)}{d\varepsilon} &= \frac{\partial \psi\left(\frac{u^0}{(1-p+\varepsilon p)}, Y\right)}{\partial u} \frac{\partial \left(\frac{u^0}{(1-p+\varepsilon p)}\right)}{\partial \varepsilon} \\ &= \frac{\partial \psi\left(\frac{u^0}{(1-p+\varepsilon p)}, Y\right)}{\partial u} \frac{\frac{\partial u^0}{\partial \varepsilon}(1-p+\varepsilon p) - pu^0}{(1-p+\varepsilon p)^2} \equiv 0 \end{aligned} \quad (45)$$

In summary we can conclude that from equations (36) and (37), the bid rent in district A increases and that in district B decreases as the earthquake occurrence probability increases under perfect information ($i = 1$). Moreover under null information ($i = 0$), the bid rents in the both districts are invariant by an increase in the earthquake occurrence probability and in the household subjective risk probability. Next task is to investigate values of the bid rent corresponding to the earthquake occurrence probability and information state.

When $p = 0$, the following equation holds for perfect information and null information ($i = 0$ and $i = 1$) from equation (27).

$$u^1|_{p=0} = u^0|_{p=0} \quad (46)$$

Therefore we have equation (47) for $p = 0$.

$$\begin{aligned} \Psi_A^1(r, u^1; 0) &= \psi(u^1|_{p=0}, y - tr) \\ &= \Psi^0(r, u^0; 0) = \psi(u^0|_{p=0}, y - tr) \end{aligned} \quad (47)$$

The bid rent in district A increases under $p > 0$ with perfect information as the earthquake occurrence probability increases, while the bid rent does not change under null information even when the earthquake occurrence probability changes. Thus we have the following inequality.

$$\Psi^0(r, u^0; p) \leq \Psi_A^1(r, u^1; p) \quad (48)$$

Similarly when $p = 0$, the next equation is realized.

$$\begin{aligned} \Psi_B^1(r, u^1; 0) &= \psi(u^1|_{p=0}, y - tr) \\ &= \Psi^0(r, u^0; 0) = \psi(u^0|_{p=0}, y - tr) \end{aligned} \quad (49)$$

The bid rent in district B decreases under $p > 0$ with perfect information as the earthquake occurrence probability increases, while the bid rent does not change under null information even when the earthquake occurrence probability changes. Therefore we have the following inequality.

$$\Psi_B^1(r, u^1; p) \leq \Psi^0(r, u^0; p) \quad (50)$$

Hence for any p and r , the following inequality holds.

$$\Psi_B^1(r, u^1; p) \leq \Psi^0(r, u^0; p) \leq \Psi_A^1(r, u^1; p) \quad (51)$$

Here the equality is realized only if $p = 0$. From equation (11), inequality (52) holds implying that the bid rent function decreases when the distance from the CBD r gets larger.

$$\frac{d\Psi(r, u)}{dr} < 0 \quad (52)$$

Here there exists a unique probability of earthquake occurrence satisfying equation (53) because of equations (37) and (52).

$$\Psi_B^1(r, u^1; \bar{p}) = R_A \quad (53)$$

Therefore district B is not used as a residential area since $\Psi_B^1(r, u^1; \bar{p}) \leq R_A$ with $p \geq \bar{p}$. From equation (28), we obtain equation (54).

$$\frac{\partial u^1}{\partial p} = 0 \quad (p \geq \bar{p}) \quad (54)$$

This implies the equilibrium utility level u^1 stays at a level for $p \geq \bar{p}$. Moreover the following inequality holds for the bid rent function.

$$\frac{\partial}{\partial r} \left(\frac{\partial \psi}{\partial u} \right) > 0 \quad (55)$$

This means that a decrease in the bid rent function becomes smaller as the household location gets further from the CBD. Hence household moving from district B to district A by earthquake information provision gets smaller when district A or district B is located beyond the CBD. And household relocation hits the peak when districts A and B are symmetrically located on either side of the CBD. An expansion in district A decreases when district A or B is located beyond the CBD, and it hits the peak when districts A and B are symmetrically located on either side of the CBD. Summarizing the above-mentioned consideration, we have the following proposition.

Proposition 1.

For a closed city with absentee landownership, the bid rent shows an increase in safe district A while a decrease in risky district B under perfect earthquake information. Moreover the area size of district A expands and that of the district B shrinks under perfect information. The bid rent in the case of null earthquake information does not change by changes in the earthquake occurrence probability and in the household subjective risk probability resulting in a symmetric distribution of the number of households and the market land rent across the city. Moreover in the case of larger district A, the impact of provision of earthquake information gets smaller for the expansion in the area size of district A and the number of households in district A as compared with the symmetric area size in districts A and B.

4. The Case with the Household Subjective Trust in Earthquake Information

In the previous section, we only consider whether the earthquake information is provided or not. Instead in this section, we consider how the household subjective trust in earthquake information changes the urban land use pattern when earthquake information is provided to households.

4.1 Model of Household Residential Choice

(1) Household Risk Perception

In this section, first of all, we model the process of household perception of earthquakes by employing the Bayesian theory. It is assumed that a household, who considers the probability of earthquake occurrence as ε ,

obtains the information of earthquake that occurs k times in ξ years through his/her experiences. Then we consider the average probability of earthquake occurrence E (risk perception) after an earthquake. Let θ be a true occurrence probability of an earthquake. Then the probability of earthquake occurrence of κ times in ξ years $P(\kappa|\theta)$ follows a binary distribution.

$$P(\kappa|\theta) = {}_{\xi}C_{\kappa}\theta^{\kappa}(1-\theta)^{\xi-\kappa} \quad (56)$$

Here we assume that any household does not know the value of θ . Also we assume that each household knows only an empirical fact that an earthquake occurs κ times in ξ years and each household estimates the value of θ based on his/her experiences. The probability distribution of θ is assumed to follow a Beta distribution .

$$f(\theta) = \frac{\Gamma(a+b)}{\Gamma(a)\Gamma(b)}\theta^{a-1}(1-\theta)^{b-1} \quad (57)$$

The risk of earthquake which a representative household a priori perceps is given by following stochastic expectation of θ .

$$\varepsilon = \int_0^1 \theta f(\theta) d\theta = \frac{a}{a+b} \quad (58)$$

Due to the Bayes theorem, each household can revise the probability distribution of θ to $f(\theta|\kappa)$ after the experience where the household perceps the probability of earthquake occurrence of κ times in ξ years.

$$\begin{aligned} f(\theta|\kappa) &= P(\kappa|\theta)f(\theta) / \int_0^1 P(\kappa|\theta)f(\theta)d\theta \\ &= \frac{\Gamma(a+b+\xi)}{\Gamma(a+\kappa)\Gamma(b+\xi-\kappa)}\theta^{a+\kappa-1}(1-\theta)^{b+\xi-\kappa-1} \end{aligned} \quad (59)$$

Hence the earthquake risk after getting the earthquake information can be expressed as the following stochastic expectation of θ .

$$E = \int_0^1 \theta f(\theta|\kappa) d\theta = \frac{\gamma\varepsilon+\xi e}{\gamma+\xi} \quad (60)$$

Here E can be interpreted as an objective risk with $\gamma = a + b$ and $e = \kappa/\xi$. It is easy to see $\lim_{\xi \rightarrow \infty} E = e$. Setting up $\tau = \xi/\gamma$, τ can be said subjective evaluation of an objective risk e for a priori perception risk ε . Therefore the ex post facto perceived risk after the information of objective risk E is denoted as follows:

$$E = \frac{\varepsilon+\tau e}{1+\tau} \quad (61)$$

The above-mentioned equation describes that the earthquake risk perceived after the earthquake experiences can be given by a linear combination of the perceived risk before the earthquake information ε and the objective risk e . In a case where any information of earthquake risk is not available, each household is assumed to recognize any point in the city as to be homogenous and to forecast the earthquake damage with the probability of $1 - \varepsilon$.

In a case where some information of earthquake risk is available, the subjective probability that the representative household forecasts the damage when an earthquake occurs is expressed by a linear combination of the subjective probability perceived before the available information $1 - \varepsilon$ and the objective probability after the earthquake information 0 or $1 - e$. According to the prospective reference theory model by Visucusi, the household conditional subjective probability $E_{\delta}(\tau; \varepsilon, e)$ in districts A and B where the representative household expects no damage when an earthquake occurs is derived as follows. Here τ refers to the household subjective trust in the earthquake information.

$$E_A(\tau; \varepsilon, e) = 1 - \frac{(1-\varepsilon)+\tau \cdot 0}{1+\tau} = \frac{\varepsilon+\tau}{1+\tau} \quad (62)$$

$$E_B(\tau; \varepsilon, e) = 1 - \frac{(1-\varepsilon)+\tau(1-e)}{1+\tau} = \frac{\varepsilon+\tau e}{1+\tau} \quad (63)$$

In a case where the representative household does not trust the earthquake information at all ($\tau = 0$), the household subjective risk perception becomes $E_\delta(0; \varepsilon, e) = \varepsilon$. Hence the household does not revise its risk perception even when any earthquake information is given. However in a case where the representative household completely trusts the earthquake information ($\tau \rightarrow \infty$), the household subjective perception coincides with the objective perception since $E_A(\infty; \varepsilon, e) = 1$ and $E_B(\infty; \varepsilon, e) = e$. Therefore the bias in the risk perception can be expressed by the difference between the objective earthquake probability 0 (or $1 - e$) and the subjective probability $1 - E_A(\tau; \varepsilon, e)$ (or $1 - E_B(\tau; \varepsilon, e)$).

The land place is indicated by $\delta = A$ or B , which denotes district A or B, and the distance from the CBD is denoted by r . Every household is assumed to consume commodities and choose its residential place so as to maximize its utility function. When there is no earthquake, each household can obtain the living condition of a_0 and enjoy its utility $u(s, z, a_0) > 0$ consuming land of s and commodity of z . However when an earthquake occurs, each household obtain a utility of $u(s, z, a_1)$ due to the worse living condition. Similar to the previous sections, we assume that the household utility after an earthquake becomes $u(s, z, a_1) = 0$ since we assume that Nankai Torough Huge Earthquake is a catastrophic disaster killing many people.

Moreover denoting the occurrence probability of an earthquake by p ($0 \leq p \leq 1$), we assume that all households know this probability. Hence the expected utility $EU_\delta^\tau(s, z, r, \tau)$ of consuming land s and composite commodity z at the location of (δ, r) can be expressed as follows:

$$EU_A^\tau(s, z, r, \tau) = (1 - p + E_A(\tau; \varepsilon, e)p)u(s, z, a_0) \quad (64)$$

$$EU_B^\tau(s, z, r, \tau) = (1 - p + E_B(\tau; \varepsilon, e)p)u(s, z, a_0) + pu(s, z, a_1) \quad (65)$$

(2) Household Behavior

Denoting the household nominal income by y and commuting cost per unit distance by t , the household behavior is expressed as follows:

$$\max_{s, z} EU_\delta^\tau(s, z, r, \tau) \quad (66)$$

$$\text{subject to } R_\delta^\tau(r)s + z + tr = y \quad (67)$$

Household demands for land and composite good at the location (δ, r) is given by the solution of the following optimization problem.

$$V_\delta^\tau(R_\delta^\tau(r), y - tr) = \{ \max_{s, z} EU_\delta^\tau(s, z, r, \tau) \mid R_\delta^\tau(r)s + z + tr = y \} \quad (68)$$

The first order necessary conditions for the problem (66) and (67) are given by the following equations with Lagrangian multiplier λ_δ^τ .

$$\begin{cases} \partial EU_\delta^\tau / \partial s = \lambda_\delta^\tau R_\delta^\tau(r) \\ \partial EU_\delta^\tau / \partial z = \lambda_\delta^\tau \\ R_\delta^\tau(r)s + z = y - tr \end{cases} \quad (69)$$

Solving equations (69), household demands for land and composite good under the subjective information trust τ are expressed as follows:

$$s_\delta^\tau = s(R_\delta^\tau(r), Y) \quad (70)$$

$$z_\delta^\tau = z(R_\delta^\tau(r), Y) \quad (71)$$

where $Y \equiv y - tr$ stands for the household net income.

The household subjective indirect utility is given by $V_\delta^\tau(R_\delta^\tau(r), Y)$ and household location choice $(r_\delta^\tau, \delta^*)$ is described by a solution in the problem $\max_{\delta, r} V_\delta^\tau(R_\delta^\tau(r), Y)$.

4.2 Land Equilibrium Model

The maximum rent that a household can pay keeping its utility u , that is, the household bid rent function $\Psi_\delta^\tau(r, u^\tau; p, e, \varepsilon, \tau)$ is defined as follows:

$$\Psi_\delta^\tau(r, u^\tau; p, e, \varepsilon, \tau) = \max_{z, s} \left\{ \frac{Y-z}{s} \mid EU_\delta^\tau(s, z, r, \tau) = u \right\} \quad (72)$$

Each point in the city is assumed to be used by the maximum rent bidder, and then the market rent function with the agricultural land rent R_A is denoted by;

$$R_\delta^\tau(r) = \max\{\Psi_A^\tau(r, u^\tau; p, e, \varepsilon, \tau), R_A\} \quad (73)$$

Here by employing the indirect utility level $V(R_\delta^\tau(r), Y)$, the equilibrium utility level under τ which satisfies $\Psi_\delta^\tau(r, u^\tau; p, e, \varepsilon, \tau) \geq R_A$ is expressed as follows:

$$u^\tau = V_A^\tau(\Psi_A^\tau(r, u^\tau; p, e, \varepsilon, \tau), Y) \quad (74)$$

$$u^\tau = V_B^\tau(\Psi_B^\tau(r, u^\tau; p, e, \varepsilon, \tau), Y) \quad (75)$$

Moreover formulae (74) and (75) are further calculated by applying $v(R_\delta^\tau(r), Y) = V_\delta^\tau(\Psi_\delta^\tau(r, u^\tau; p, e, \varepsilon, \tau), Y)/(1 - p + E_\delta(\tau; \varepsilon, e)p)$ as follows:

$$u^\tau = (1 - p + E_A(\tau; \varepsilon, e)p)v(\Psi_A^\tau(r, u^\tau; p, q, \varepsilon, \tau), Y) \quad (76)$$

$$u^\tau = (1 - p + E_B(\tau; \varepsilon, e)p)v(\Psi_B^\tau(r, u^\tau; p, q, \varepsilon, \tau), Y) \quad (77)$$

Solving equations (76) and (77) with respect to $\Psi_\delta^\tau(r, u^\tau; p, q, \varepsilon, \tau)$, the equilibrium bid rent can be obtained by using Solo's bid rent function $\psi(u, Y)$.

$$\Psi_A^\tau(r, u^\tau; p, e, \varepsilon, \tau) = \psi\left(\frac{u^\tau}{1 - p + E_A(\tau; \varepsilon, e)p}, Y\right) \quad (78)$$

$$\Psi_B^\tau(r, u^\tau; p, e, \varepsilon, \tau) = \psi\left(\frac{u^\tau}{1 - p + E_B(\tau; \varepsilon, e)p}, Y\right) \quad (79)$$

Moreover in a case where all households do not trust the earthquake information ($\tau = 0$), the equilibrium bid rent is calculated as follows:

$$\Psi_\delta^\tau(r, u^\tau; p, e, \varepsilon, 0) \equiv \Psi^0(r, u^0) \quad (80)$$

Denoting the distance between the CBD and the city boundary in the district δ with the information state i by \bar{r}_δ^τ , we obtain the following equations.

$$\Psi_A^\tau(\bar{r}_a^\tau, u^\tau; p, e, \varepsilon, \tau) = \Psi_B^\tau(\bar{r}_c^\tau, u^\tau; p, e, \varepsilon, \tau) = R_A \quad (81)$$

where \bar{r}_a^τ refers to the distance from the CBD to the boundary between district A and the agricultural area, \bar{r}_b^τ depicts the distance from the CBD to the boundary between districts A and B, and \bar{r}_c^τ expresses the distance from the CBD to the boundary between district B and the agricultural area.

The number of households living in the unit distance with width h , n_δ^τ , is depicted as follows:

$$n_\delta^\tau(R_\delta^\tau(r), Y) = \frac{h}{s(R_\delta^\tau(r), Y)} \quad (82)$$

Hence the total number of households N in the city under the equilibrium land use is calculated as follows:

$$N = \int_0^{\bar{r}_a^\tau} \left\{ \frac{h}{s(\Psi_A^\tau(r, u^\tau; p, e, \varepsilon, \tau), Y)} \right\} dr + \int_0^{\bar{r}_b^\tau} \left\{ \frac{h}{s(\Psi_A^\tau(r, u^\tau; p, e, \varepsilon, \tau), Y)} \right\} dr + \int_{\bar{r}_b^\tau}^{\bar{r}_c^\tau} \left\{ \frac{h}{s(\Psi_B^\tau(r, u^\tau; p, e, \varepsilon, \tau), Y)} \right\} dr \quad (83)$$

Solving equations (76), (77), (81) and (83), we endogenously obtain the equilibrium utility level u^τ , the equilibrium city boundary \bar{r}_δ^τ and the equilibrium bid rent function $\Psi_\delta^\tau(r, u^\tau; p)$.

4.3 Comparative Static Analysis of Equilibrium Location

In this section we consider the impacts of earthquake information provision and the household subjective trust in the earthquake information.

First $1 - p + \frac{\varepsilon + \tau}{1 + \tau} p \geq 1 - p + \frac{\varepsilon + \tau e}{1 + \tau} p$, equation (78), equation (79) and $\frac{\partial v(R(r), Y)}{\partial R(r)} < 0$ hold. Therefore the equilibrium bid rent under the perfect information provision, the following inequality is realized for arbitrary $r, u^\tau, p, e, \varepsilon$ and τ .

$$\Psi_A^\tau(r, u^\tau; p, e, \varepsilon, \tau) \geq \Psi_B^\tau(r, u^\tau; p, e, \varepsilon, \tau) \quad (84)$$

In the above-mentioned inequality, the equality holds when $\tau p(1 - e) = 0$. The equilibrium utility level u^τ takes the same value at different points. Therefore differentiation of equation (68) with respect to r becomes zero.

$$\frac{\partial V_{\delta}^{\tau}(\Psi_{\delta}^{\tau}, Y)}{\partial R_{\delta}^{\tau}} \frac{\partial \Psi_{\delta}^{\tau}(r, u^{\tau})}{\partial r} - \frac{\partial V_{\delta}^{\tau}(\Psi_{\delta}^{\tau}, Y)}{\partial Y} t = 0 \quad (85)$$

Equation (85) yields equation (86).

$$\frac{\partial V_{\delta}^{\tau}(\Psi_{\delta}^{\tau}, Y) / \partial R_{\delta}^{\tau}}{\partial V_{\delta}^{\tau}(\Psi_{\delta}^{\tau}, Y) / \partial Y} \frac{\partial \Psi_{\delta}^{\tau}(r, u^{\tau})}{\partial r} = t \quad (86)$$

Here applying Roy's identity, we have;

$$\frac{\partial V_{\delta}^{\tau}(\Psi_{\delta}^{\tau}, Y) / \partial R_{\delta}^{\tau}}{\partial V_{\delta}^{\tau}(\Psi_{\delta}^{\tau}, Y) / \partial Y} = s(\Psi_{\delta}^{\tau}(r, u^{\tau}), Y) \quad (87)$$

From equations (88) and (83), we obtain equation (88).

$$\frac{1}{s(\Psi_{\delta}^{\tau}(r, u^{\tau}), Y)} = - \frac{\partial \Psi_{\delta}^{\tau}(r, u^{\tau})}{\partial r} \frac{1}{t} \quad (88)$$

Substituting equation (88) to equation (83), the total population in the city can be expressed as follows:

$$N = \frac{h}{t} \{ 2\Psi_A^{\tau}(0, u^{\tau}) + \Psi_B^{\tau}(\bar{r}_b^{\tau}, u^{\tau}) - \Psi_A^{\tau}(\bar{r}_b^{\tau}, u^{\tau}) - 2R_A \} \quad (89)$$

In this study we assume a closed city, hence the number of households does not change with respect to the household subjective trust in earthquake information. Thus the following equation is obtained.

$$\begin{aligned} \frac{dN}{d\tau} &= \frac{h}{t} \left\{ 2 \frac{d\Psi_A^{\tau}(0, u^{\tau}; p, e, \varepsilon, \tau)}{d\tau} + \frac{d\Psi_B^{\tau}(\bar{r}_b^{\tau}, u^{\tau}; p, e, \varepsilon, \tau)}{d\tau} - \frac{d\Psi_A^{\tau}(\bar{r}_b^{\tau}, u^{\tau}; p, e, \varepsilon, \tau)}{d\tau} \right\} \\ &= \frac{h}{t} \left\{ 2 \frac{\partial \psi \left(\frac{u^{\tau}}{1-p+\frac{\varepsilon+\tau}{1+\tau}p}, y \right)}{\partial u} \frac{\partial}{\partial \tau} \left(\frac{u^{\tau}}{1-p+\frac{\varepsilon+\tau}{1+\tau}p} \right) + \frac{\partial \psi \left(\frac{u^{\tau}}{1-p+\frac{\varepsilon+\tau e}{1+\tau}p}, y - t\bar{r}_b^{\tau} \right)}{\partial u} \frac{\partial}{\partial \tau} \left(\frac{u^{\tau}}{1-p+\frac{\varepsilon+\tau e}{1+\tau}p} \right) - \frac{\partial \psi \left(\frac{u^{\tau}}{1-p+\frac{\varepsilon+\tau}{1+\tau}p}, y - t\bar{r}_b^{\tau} \right)}{\partial u} \frac{\partial}{\partial \tau} \left(\frac{u^{\tau}}{1-p+\frac{\varepsilon+\tau}{1+\tau}p} \right) \right\} \\ &= \frac{h}{t} \left\{ \left(2 \frac{\partial \psi \left(\frac{u^{\tau}}{1-p+\frac{\varepsilon+\tau}{1+\tau}p}, y \right)}{\partial u} - \frac{\partial \psi \left(\frac{u^{\tau}}{1-p+\frac{\varepsilon+\tau}{1+\tau}p}, y - t\bar{r}_b^{\tau} \right)}{\partial u} \right) \frac{\partial}{\partial \tau} \left(\frac{u^{\tau}}{1-p+\frac{\varepsilon+\tau}{1+\tau}p} \right) + \frac{\partial \psi \left(\frac{u^{\tau}}{1-p+\frac{\varepsilon+\tau e}{1+\tau}p}, y - t\bar{r}_b^{\tau} \right)}{\partial u} \frac{\partial}{\partial \tau} \left(\frac{u^{\tau}}{1-p+\frac{\varepsilon+\tau e}{1+\tau}p} \right) \right\} \\ &\equiv 0 \end{aligned} \quad (90)$$

In order to examine the economic impact of household subjective trust in earthquake information τ on the bid rent, we investigate the sign of each term in equation (90). First we obtain inequality (91) from $\frac{\partial \psi(u, y)}{\partial u} < 0$.

$$\frac{\partial \psi \left(\frac{u^{\tau}}{1-p+\frac{\varepsilon+\tau}{1+\tau}p}, y \right)}{\partial u}, \frac{\partial \psi \left(\frac{u^{\tau}}{1-p+\frac{\varepsilon+\tau e}{1+\tau}p}, y - t\bar{r}_b^{\tau} \right)}{\partial u}, \frac{\partial \psi \left(\frac{u^{\tau}}{1-p+\frac{\varepsilon+\tau}{1+\tau}p}, y - t\bar{r}_b^{\tau} \right)}{\partial u} < 0 \quad (91)$$

Since the bid rent function $\psi(u, Y)$ is continuously increasing function in Y and continuously decreasing function in u , we get the following inequality.

$$\psi \left(\frac{u^{\tau}}{1-p+\frac{\varepsilon+\tau}{1+\tau}p}, y - t\bar{r}_b^{\tau} \right) < \psi \left(\frac{u^{\tau}}{1-p+\frac{\varepsilon+\tau}{1+\tau}p}, y \right) \quad (92)$$

Since $u > 0$ and $Y > 0$, the following inequality holds when equation (92) is realized.

$$\frac{\partial \psi \left(\frac{u^{\tau}}{1-p+\frac{\varepsilon+\tau}{1+\tau}p}, y \right)}{\partial u} < \frac{\partial \psi \left(\frac{u^{\tau}}{1-p+\frac{\varepsilon+\tau}{1+\tau}p}, y - t\bar{r}_b^{\tau} \right)}{\partial u} < 0 \quad (93)$$

When inequality (93) holds, the following inequality is realized.

$$\left(2 \frac{\partial \psi \left(\frac{u^{\tau}}{1-p+\frac{\varepsilon+\tau}{1+\tau}p}, y \right)}{\partial u} - \frac{\partial \psi \left(\frac{u^{\tau}}{1-p+\frac{\varepsilon+\tau}{1+\tau}p}, y - t\bar{r}_b^{\tau} \right)}{\partial u} \right) < 0 \quad (94)$$

When inequality (94) holds, it is necessary that $\frac{\partial}{\partial \tau} \left(\frac{u^\tau}{1-p+\frac{\varepsilon+\tau}{1+\tau}p} \right)$ and $\frac{\partial}{\partial \tau} \left(\frac{u^\tau}{1-p+\frac{\varepsilon+\tau e}{1+\tau}p} \right)$ have different sign in order to satisfy equality (90). Hence under the conditions $p(1-e)(e-\varepsilon) \neq 0$ and $0 < \varepsilon < 1$, we have;

$$\frac{\partial}{\partial \tau} \left(\frac{u^\tau}{1-p+\frac{\varepsilon+\tau}{1+\tau}p} \right) \frac{\partial}{\partial \tau} \left(\frac{u^\tau}{1-p+\frac{\varepsilon+\tau e}{1+\tau}p} \right) < 0 \quad (95)$$

That is, the earthquake occurrence probability is not zero, there is a possibility that damage is caused when an earthquake occurs and there is a gap between the objective risk perception and the subjective risk perception. Under these conditions the following inequalities hold.

$$\frac{\partial}{\partial \tau} \left(\frac{u^\tau}{1-p+\frac{\varepsilon+\tau}{1+\tau}p} \right) < 0 \quad \text{and} \quad 0 < \frac{\partial}{\partial \tau} \left(\frac{u^\tau}{1-p+\frac{\varepsilon+\tau e}{1+\tau}p} \right) \quad (96)$$

Hence we have the following inequalities.

$$\frac{\psi_A^\tau(r, u^\tau; p, e, \varepsilon, \tau)}{d\tau} = \frac{\partial \psi \left(\frac{u^\tau}{1-p+\frac{\varepsilon+\tau}{1+\tau}p}, Y \right)}{\partial u} \frac{\partial}{\partial \tau} \left(\frac{u^\tau}{1-p+\frac{\varepsilon+\tau}{1+\tau}p} \right) > 0 \quad (97)$$

$$\frac{\psi_B^\tau(r, u^\tau; p, e, \varepsilon, \tau)}{d\tau} = \frac{\partial \psi \left(\frac{u^\tau}{1-p+\frac{\varepsilon+\tau e}{1+\tau}p}, Y \right)}{\partial u} \frac{\partial}{\partial \tau} \left(\frac{u^\tau}{1-p+\frac{\varepsilon+\tau e}{1+\tau}p} \right) < 0 \quad (98)$$

From formulae (97) and (98), it can be said that the bid rent increases in district A while it decreases in district B as the subjective trust in earthquake information increases. Moreover when $p(1-e)(e-\varepsilon) = 0$, we have the following formulae.

$$\begin{aligned} \frac{\psi_A^\tau(r, u^\tau; p, e, \varepsilon, \tau)}{d\tau} &= \frac{\partial \psi \left(\frac{u^\tau}{1-p+\frac{\varepsilon+\tau}{1+\tau}p}, Y \right)}{\partial u} \frac{\partial}{\partial \tau} \left(\frac{u^\tau}{1-p+\frac{\varepsilon+\tau}{1+\tau}p} \right) \\ &= \frac{\partial \psi \left(\frac{u^\tau}{1-p+\frac{\varepsilon+\tau}{1+\tau}p}, Y \right)}{\partial u} \frac{\partial u^\tau}{\partial \tau} (1-p+\frac{\varepsilon+\tau}{1+\tau}p) - u^\tau \frac{1-\varepsilon}{(1+\tau)^2} p}{(1-p+\frac{\varepsilon+\tau}{1+\tau}p)^2} = 0 \end{aligned} \quad (99)$$

$$\begin{aligned} \frac{\psi_B^\tau(r, u^\tau; p, e, \varepsilon, \tau)}{d\tau} &= \frac{\partial \psi \left(\frac{u^\tau}{1-p+\frac{\varepsilon+\tau e}{1+\tau}p}, Y \right)}{\partial u} \frac{\partial}{\partial \tau} \left(\frac{u^\tau}{1-p+\frac{\varepsilon+\tau e}{1+\tau}p} \right) \\ &= \frac{\partial \psi \left(\frac{u^\tau}{1-p+\frac{\varepsilon+\tau e}{1+\tau}p}, Y \right)}{\partial u} \frac{\partial u^\tau}{\partial \tau} (1-p+\frac{\varepsilon+\tau e}{1+\tau}p) - u^\tau \frac{1-\varepsilon}{(1+\tau)^2} p}{(1-p+\frac{\varepsilon+\tau e}{1+\tau}p)^2} = 0 \end{aligned} \quad (100)$$

That is, when the earthquake occurrence probability is zero or damage is not caused by an earthquake or there is not a gap between the objective risk perception and the subjective risk perception, provision of earthquake information has no impact on the formation of household risk perception resulting in the fact that the locational distribution of the bid rent are the same in districts A and B. Moreover the following inequality for the bid rent function is realized.

$$\frac{\partial}{\partial r} \left(\frac{\partial \psi}{\partial u} \right) > 0 \quad (101)$$

This implies that a decrease in the bid rent function becomes smaller as the household location gets further from the CBD. Hence household relocation from district B to district A by an increase in household subjective trust in earthquake information gets smaller when district A or district B is located beyond the CBD. And household relocation hits the peak when districts A and B are symmetrically located on either side of the CBD. An expansion in district A gets smaller when district A or B is located beyond the CBD, and it hits the peak when districts A and B are symmetrically located on either side of the CBD. Summarizing the above-mentioned discussion, we have Proposition 2.

Proposition 2.

In a closed city with absentee landownership, the equilibrium bid rent with provision of earthquake information increases in district A and decreases in district B as the household subjective trust in earthquake information τ increases. Moreover the city boundary in district A expands while that in district B shrinks as household subjective trust in earthquake information τ increases. In a case where any household does not trust the earthquake information, the equilibrium bid rent shows a symmetric distribution on either side of the CBD. By an increase in the household subjective trust in earthquake information, households relocate from district B to district A resulting in an expansion of the area size of district A. And this impact hits the highest when the two districts are symmetrically located on either side of the CBD.

5. Concluding Remarks

In a case where the household subjective trust in earthquake information is not taken into account, the number of households and the equilibrium bid rent symmetrically distribute on either side of the CBD if earthquake information is not provided at all. However if earthquake information is provided, the bid rent shows a decrease in the risky district while it depicts an increase in the safe district. Since the land with a lower bid rent than the agricultural land rent is not used as residential area, the size of residential area in the risky district shrinks and that in the safe district gets larger. From this fact it can be concluded that earthquake information provision enables households to move from the risky district to the safe district prior to the earthquake occurrence resulting in a reduction of damage on household life and asset. This impact hits the peak when the safe and risky districts are symmetrically located on either side of the CBD.

When household subjective trust in earthquake information is taken into account, the bid rent in the risky district decreases while that in the safe district increases as household subjective trust in earthquake information gets higher. Hence the size of residential area in the risky district shrinks while that in the safe district expands. However when any household does not trust the earthquake information at all, the bid rent symmetrically distributes on either side of the CBD. Thus an increase in household trust in earthquake information relocates households from the risky district to the safe district prior to the earthquake occurrence resulting in a reduction of damage on household life and asset. This impact hits the peak when the safe and risky districts are symmetrically distributed on either side of the CBD.

From above-mentioned discussions we can conclude that if the risky district spreads across the CBD with a larger size than that of the safe district, the disaster damage prevention effect by provision of earthquake information can be enhanced by improving safeness of the risky district.

References

- [1] Kentaro Yamaguchi, Yuuichi Tadano, Narinao Tanaka and Norio Okada, Impact of Information Provision for Huge Disaster Risk in a Monocentric City, *Infrastructure Planning Review*, Vol. 16, pp.333-340, 1999 (in Japanese)
- [2] Kentaro Yamaguchi, Yuuichi Tadano and Norio Okada, Analysis of Impact of Bias in Risk Perception on Provision of Disaster Information, *Infrastructure Planning Review*, Vol. 17, pp.327-336, 2000 (in Japanese)
- [3] Viscusi, K.W., *Fatal Tradeoffs : Public and Private Responsibilities for Risk*, New York: Oxford University Press, 1992
- [4] Toshitaka Katada and Yasushi Oikawa, A Study on Publication Effect of a Hazard Map Focussing on Flood Experience and Disaster Conciousness, *Proceeding of Infrastructure Planning*, Vol. 21 (1), pp.331-334, 1998 (in Japanese)
- [5] Takayuki Ueda, Benefit Evaluation of Disaster Prevention Investment - Based on the Concept of Uncertainty and Disequilibrium, *Infrastructure Planning Review*, Vol. 14, pp.17-34, 1997 (in Japanese)
- [6] Masahisa Fujita, *Urban Economic Theory*, Cambridge University Press, 1989