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An Empirical Application of the Linear Programming Model for Agricultural Land Use Planning through the Valuation of Negative Externalities Caused by Abandoning Farmland in Marginal Areas

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Farmland abandonment has been a serious problem in marginal areas in Japan. One of the main disadvantages of farmland abandonment is the effects of negative externalities on the adjacent farmlands, such as increased insect damage, weed growth, and maintenance costs of common facilities. In this paper, an empirical application of a linear programming model is introduced, which can deal with unknown values of negative externalities caused by adjacent abandoned farmlands. The unit cost of externalities caused by farm abandonment is calculated through observed land use and farming practices. The optimized result is able to reproduce the observed land use pattern at a significant hitting ratio. By substituting calculated value into the model of current cropping plots, we can suggest the optimal land use plan for the limited labour input in the changing future. The farmland plots in the suggested land use plan are not scattered spatially, reflecting the effect of externalities.

Key words: land use planning, externality, linear programming, positive mathematical programming, geographical information system (GIS), marginal areas, rice paddy.

1. Introduction

Parallel with aging and depopulation, farmland abandonment has been a serious problem in the marginal areas of Japan. In such areas, there is still considerable potential for groups of farmers to become economically vital if they can concentrate relatively better farmland under a governmental support (Kashiwagi [6]). The reality, however, is that the abandonment of uneven farmland based on the decisions of individual farm owners has been rampant. A single unplanned instance of a farm being abandoned can cause a subsequent chain-reaction due to the negative externalities. Considering the externality effects between farmland plots and plot-based productivity, there is a need to implement regional land-use planning.

One possible approach to evaluate externalities is through the hedonic model with the use of farmland prices or rents, as applied to the impact evaluation of constructing a nuclear power station (Folland and Hough [2]). However, farmland prices or rents determined the basis of on individual negotiations are not always representative of the agricultural value of land. A far more serious problem is the case of farms being abandoned for which land prices remain undetectable.

Another available method is making use of an empirical approach with variables of nearby land use and reflecting the externalities in the model. For example, Morita, Kobayashi, and Morishita [8] forecasted impacts of changes in contiguous land use in Kagawa Prefecture, Japan, by employing 10-meter-mesh land-use data. One of the limitations of such a method is the unavailability for land-use prediction due to the fluctuations in input and output prices. Another problem is the

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difficulty in measuring economic responses from the local stakeholders.

Generally, programming models are superior to empirical models in terms of providing optimal plans for changing situations, considering detailed production structures. Previously, programming models were widely applied to regional agricultural planning. Tsuchida [13] proposed a planning method for groups of field plots with heterogeneous capabilities located at different distances from the farmer's house. Tsuruoka [14] compared the calculated outputs from combinations of field plots with different levels of improvement, distance, and consolidation. Others suggested methods for considering externalities such as nitrate runoff (Moxey [9]) and the abandonment of farms (Yagi et al. [17]). However, using a programming model requires the meticulous selection of coefficients due to the inapplicability of statistical verification.

Kimura [7: pp. 54-55] classified the probable negative externalities caused by the abandonment of farms as follows : (a) direct effects on nearby farm plots such as damage or an increase in costs due to the proliferation of weeds, pests, wild birds, and insufficient sunlight and (b) indirect effects on shared facilities such as irrigation ditches or farm roads, which are maintained by the nearby farmers or owners of the farmlands. The number of old (for the year 1950) local authority boundaries that suffered from negative externality problems as a result of farm abandonment was surveyed for the Census of Agriculture and Forestry of 1995. The results showed crop damage due to insects, farmland devastation, and wild animals or birds. Even though economic valuations were not conducted, Yagi [15] estimated the threshold levels of farm abandonment in the area where local farmers recognized it as a problem.

Unless economic valuations by experimental approaches such as on-farm observations or bookkeeping records of hundreds of field plots were available within the limits of our budget, an empirical economic model would be a reasonable method to evaluate the negative externalities. In this research, a linear programming (LP) model is adopted for empirical use, and externalities are calculated and maps for farmland conservation are planned on a field-plot basis. Hayashi [3] pointed that the straightforward uses of mathematical programming are not always able to give realistic solutions and suggested the application of positive mathematical programming (PMP). In this case, a normal linear programming model can be written as

$$\max f(x),$$
$$Ax \leqq b, \quad x \geqq 0 \qquad (1)$$

where $f(x)$ is an objective function consisting of row vector x denoting activities, matrix A denoting the linear technology coefficients, and column vector b represents resource constraints. The positive or empirical problem can be formalized to obtain $f(x)$, where the observed x^* is an optimal solution. In the next step, a newly obtained $f(x)$ produces realistic solutions for the baseline situation.

Howitt [5] calculated quadratic yield coefficients using PMP based on observed land use and output/input prices. Preckel, Harrington, and Dubman [10] forecasted the area of genetically modified crops. In these studies, the shadow prices for x^* were used for the reproducing procedure of $f(x)$. However, due to relatively fixed boundaries, land-use decisions are typically based on each field plot in which a farmer decides on either using the plot ($x^*=1$) for agriculture or not ($x^*=0$). This condition prevents the model from producing appropriate shadow prices.

In this paper, we propose a solution in which a realistic $f(x)$ can be chosen on the basis of the hitting ratio of $f(x)$ against the real x^*. In order to be effective, this method is required to be able to reproduce the current land use through LP optimization.

Previous findings support the assumption that farm abandonment has gradually occurred in the case of unproductive field plots under the constrained condition of machinery operation, although the owners' individual circumstances may partly reflect on the land-use. For example, Senda [12] analyzed the factors determining farm abandonment with the help of individual data obtained from the Agricultural Census of the Chugoku region and concluded that farm sizes, sales of agricultural produce, and the ownership of machinery influence the prevention of this problem. Based on the estimation of regression models with municipality-level data, Hirano [4] found that decline in the farm work force, low profitability, and the low percentage of cooperative operations for rice production resulted in farm abandonment. Endo [1] clarified that the prevailing use of farmland in mountainous areas was determined by the possibility of machinery operation, proportion of agricultural income in the household, irrigation, yields, and accessibility. Note that incidental circumstances of owners and field-plot-based capabilities are considered to be independent of each other. If the individual circumstances of land owners partly determined land-use in the long-term period, the hitting ratio of the optimized solution based on farmland productivity would be decreased. This is because the existence of any independent drivers other than those that are explained in the model would reduce the hitting ratio. Therefore, the hitting ratio can assess the goodness of fit of reproduction by using the LP model.

In order to improve the hitting ratio for reproducing the current situation, the negative externalities caused by farm abandonment are also considered in this paper. This is based on an assumption by which the spatial proximity between unused and present farmland effects productivity and the current land use accordingly. In this case, a possible problem arises in the case where consecutive farm plots are unused due to the owners' individual contexts, which might consequently be misunderstood as a result of externalities.

This problem can be clarified by using existing statistics. Table 1 summarizes the trends of the number of farm households, farmland areas, family sizes of individual farm households, the agricultural work force, and the share of small size (less than 1 ha) farms in the Chugoku region for the period between 1975 and 2000. Both the number of farm households and the area of farmland have decreased by approximately 60% during the period. However, the work force and households have declined more rapidly. This gap implies a gradual decline in the number of farm field plots rather than the simultaneous occurrence of retirements from farming and abandoning all the farm plots at the same time.[1] Moreover, the share of small farms accounts for half of the farmland, which implies that there are not many consecutive field plots owned by a single farmer. Hence, the case where, regardless of productivity, consecutive farms have been abandoned due to the owner's circumstances is considered to be relatively rare.

In this paper, the total agricultural income in a certain spatial range is adopted as an objective of optimization. This spatial range includes one or a few rural communities in which plot-based land-use planning can be discussed by farmers and residents. Since other farmers are unable to rent unproductive farm plots, these fields are more likely to be left unused than the better field plots. Therefore, the optimization of total farm income in the area would reflect the current land use at a sufficient level of the hitting ratio.

Another point to be noted is the length of the time period for which changes in land use are observed. Typically, land is one of the most fixed factors of inputs and farmers need a considerable time period for adjustment. Thus, in order to reduce the effect of timing gaps due to the owners' generation differences, two points in time should be separated by a minimum interval of ten years,

Table 1. Changes in the agricultural structure in the Chugoku Region (1975-2000)

Year	Number of farm households (10,000 hhs)	Area of agricultural land (10,000 ha)	Population in farm households (10,000)	Agricultural work force (10,000)	Share of agricultural land area cultivated as small farms (<1 ha)
1975	51.0	32.2	215.5	140.4	0.59
	1.00	1.00	1.00	1.00	—
2000	31.6	21.2	124.0	83.6	0.54
	0.62	0.66	0.58	0.60	—

Source: Agricultural Census, Japan. The figures below indicate the proportions to those in 1975.

provided that data availability allows it. If there were considerable changes in socioeconomic circumstances and unused farm plots were cultivated, the optimization model should account for such costs of reutilizing unused farmland given the current agricultural productivities.

In the next section, the LP model and the procedure of application for farmland planning are explained.

2. The Methodology

1) Study area

The study area—Y district in H village—is located in the most remote part of the Iwami region of Shimane Prefecture. For the data set, we chose 198 plots (11.6 ha) of rice fields and 115 plots (3.0 ha) of unused farmland. These plots are cultivated by 37 farmers including a few farmers who hold more than 1 ha of farmland. In this district, a consensus has been reached with regard to commencing communal agricultural operations and some plans are being designed for the land use.

To realize the current (*i.e.*, observed) land use including farm abandonment, the past use of current forest or wasteland should be investigated. As noted in the previous section, large fluctuations in socioeconomic circumstances would result in re-cultivation. This possibility can be neglected because the size of total farmland area in the mountainous regions has declined monotonically since the rapid economic growth in the 1960s. Figure 1 depicts the current land-use pattern illustrated through a comparison of aerial photographs taken at two different points in time (*i.e.*, 1975 and 2000), supplemented by the field survey conducted in 2003. The consolidated plots located in the center of the study area are under rice cultivation, while unconsolidated small plots located on the mountain-side tend to be unused. In a case study of the same area, Sakuno [11] suggested that relatively unproductive field plots with poor accessibility were likely to be left unused.

2) Linear programming model with perfect information

Model building is initiated from a linear programming model using perfect information on plot-based data, such as area, profit and technical coefficients, total labor capacity, and the unit cost of negative externalities caused by farm abandonment. [2] The objective function for optimizing plot-based land use is

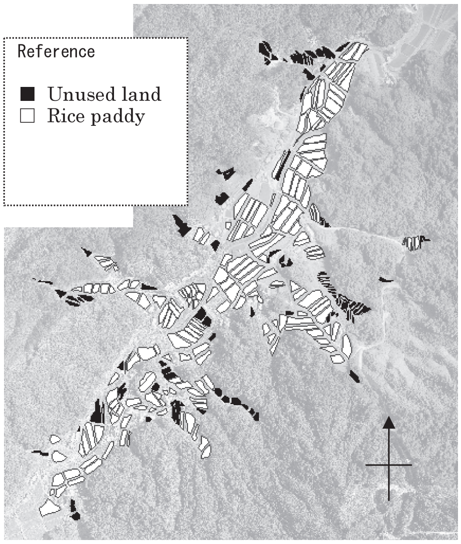

Figure 1. Observed land use patternof the study area (2003)

$$\max \pi = \sum_i r_i \cdot a_i \cdot X_i - \sum_i c \cdot E_i \quad \text{objective function} \quad (2)$$

where, π represents a total regional output value (1,000 JPY) to be maximized,

X_i is a binary integer variable representing the land-use decision (1 : cropping, 0 : not cropping) for plot i,

E_i is the land area (10 a) affected by externalities when plot i is unused,

r_i is a constant coefficient indicating profit (1,000 JPY/10 a) for land unit i.

a_i is area of field plot (10 a), and

c is the unknown unit cost of externalities (1,000 JPY/10 a).

We append a set of inequalities from which we can derive the farmland area affected by externalities.

$$-(\sum_h d_{hi} \cdot a_h) \cdot X_i + \sum_h d_{hi} \cdot a_h \cdot X_h - E_i \leqq 0 \quad \text{externality constraints} \quad (3)$$

where, d_{hi} represents the proximity between plots i and h ($h \neq i$) (1 : contiguous, 0 : not contiguous).

To provide a simple explanation about externality constraints, say if $X_i=0$ and any of X_h are 1, then E_i will be given positive numbers, where positive E_i implies the existence of externalities by the unused plot i.

Additionally, inequality (4) shows that the total labor requirements should not exceed the labor resource scarcity, $wmax$.[3)]

$$\sum_i w_i \cdot a_i \cdot X_i + \sum_z m_z \cdot M_z \leq wmax$$

total labor constraint (4)

where, w_i represents a labor requirement for the harvest (hour/10 a) for land plot i,
m_z is unit time (hour/frequency) for traveling between farmland parcel z, and M_z (time) is an integer variable representing the frequency of moving to parcel z.

If moving occurs every six hours of harvesting, such constraint is written as

$$\sum_i w_i \cdot zo_i \, a_i \, X_i - 6 \cdot M_z \leq 0$$

moving constraint (5).

where, zo_i is an index representing plot i within parcel z (1 : within the parcel z, 0 : outside of the parcel z).

3) Calculating negative externalities (Step 1)

Then, the problem comprises calculating the unknown c and d_{hi}. If the current land use X^*_i (1 : cropping, 0 : not cropping) is known by observing the changes in land use, optimized solution$\hat{X}_i$ for arbitrary c and d_{hi} can be assessed based on the following hitting ratio $p(c, d_{hi})$

$$p = \sum_i |\hat{X}_i - X^*_i|/n \qquad (6)$$

where, n represents the number of plots. Under the assumption that observed X^*_i optimizes total farm income, a presumable combination of c and d_{hi} can be chosen when hitting ratio p is maximized.

The current labor input, $wmax^*$, is calculated based on the following equation (7) by substituting the observed x^* and the given parameters.

$$wmax^* = \sum_i w_i \cdot a_i \cdot x^*_i + \left(\sum_i \sum_z m_z \cdot w_i \cdot a_i \cdot x^*_i/6\right) \qquad (7)$$

4) Suggesting an optimized land use plan (Step 2)

In the next step (Step 2), by substituting the calculated value c, d_{hi} into the LP model of present cropping plots ($x^*=1$), we can calculate the optimal land use for the limited labor input, $wmax$, in the future.

3. Application

1) Data

The given baseline coefficients for the model were prepared through a field survey conducted in the Y district from August to October of 2003. Managers of all the 15 farms holding more than 40 a of farmland were visited and given survey sheets. These sheets were collected after the rice harvest with some supplementary interviews. The sample accounts for 84% of the total cropping area within the study area. The survey includes farm characteristics, such as location, irrigation, area of cultivated field plots, and machinery. At the same time, fertility management appropriateness, damage caused by lodging and the production of rice, and labor input in terms of harvesting were also surveyed. The total sample size of the field plots was 73, although some items are incomplete. The amount of solar radiation is based on the 50-meter-mesh data.[4)]

Coefficients were prepared for all the field plots (313 plots) in the Y district as summarized in Table 3. Plot area a_i is derived from the orthorectified aerial photographs. zo_i, the parcel of field plots irrigated by the same rain-fed irrigation or irrigation network, is generated based on interviews and field study. The proximity of the plots, d_{hi}, is determined by the geographic information system (GIS) whether any plots are within the range of 20 m, 25 m, or 30 m from the center of a plot.[5)]

The profit and technical coefficients for labor related to harvesting are estimated by using the information available from the interviews (Table 2). The profit coefficient r is calculated from the yield Y, output price P, and variable cost V. The booked yield in the survey result reported in Table 2 is used as a dependent variable for the estimation of the rice yield function ; independent variables are longitude and latitude that represent the relative locations in the Y district and the irrigation availability. The output price, 267 JPY/kg shipped for JA, is derived from the results of the interview. Variable cost, 28, 565 JPY/

Table 2. Summary of sample farms and field plots

No.	Characteristics of sample farms						Characteristics of sample field plots						
	Rice cropping area (a)	Rice planting machine		Combine harvester		Grain drying machine (koku)	The number of sample plots	Plots damaged by rice lodging	Inappropriate fertility management	Rain-fed paddy	Solar radiation in July (Mj/m²•d)	Average rice yield (kg/a)	Average labor input for harvest (hr/plot)
		Number of rows	For riding	Number of rows	tank type								
1	156	4	Yes	2	Bag	15, 13	4	4	0	0	7. 63	—	—
2	123	4	Yes	2	Bag	12, 15	3	0	3	0	7. 62	36. 0	2. 0
3	76	4	Yes	2	Bag	12	1	0	1	0	7. 70		7. 0
4	66	4	Yes	2	Bag	14	2	0	2	0	7. 60	—	—
5	63	—		—		—	4	0	0	0	7. 61	49. 7	—
6	55	4	Yes	2	Grain tank	15, 12	16	4	16	13	7. 58	48. 8	1. 6
7	54	4	Yes	2	Bag	8	4	0	4	3	7. 65	51. 3	4. 9
8	53	2	No	(Binder)		NA	5	1	0	0	7. 60	57. 0	—
9	52	4	Yes	2	Bag	12	6	0	0	0	7. 62	—	—
10	51	4	No	2	Bag	12	12	0	1	3	7. 60	56. 8	1. 5
11	50	2	No	NA		NA	4	0	1	3	7. 54	—	—
12	46	4	Yes	2	Bag	8, 8	1	0	0	0	7. 56	—	—
13	43	2	No	NA		NA	3	0	2	2	7. 63	32. 8	0. 5
14	42	4	Yes	2	Bag	18	2	0	0	0	7. 71	43. 0	—
15	41	4	Yes	2	Bag	12	6	6	6	0	7. 66	43. 6	2. 8

Source: Field survey conducted from August to October, 2003. Survey sheets were handed out before the rice harvest and collected after it.
Note: One "koku" is approximately 278. 3 liters.

10 a, is based on government statistics of rice production costs (Shimane Pprefecture, Production year 2002).

The result of a previous study (Yagi et al. [16]) can be applicable to plot-based expected labor requirement in the harvesting season, w_i (hour/10 a), taking the effect of lodging related damage into consideration. In the case of a normal harvest, that is, 58 plots in total, Ts is calculated and the Pearson's correlation with farmers' stated labor inputs is revealed to be 0. 86. For the lodged rice harvest of 15 plots, calculated Tf shows a correlation of 0. 64 with the stated value. The probability of lodging, PF, is estimated using a logistic regression model, where the dependent variable is the occurrence of rice lodging and the independent variables are the probability of inappropriate fertility management (0. 53 for irrigated plots and 0. 35 for rain-fed ones) and solar radiation in July.

2) Assessing the negative externalities

(1) Empirical pre-approach

Before employing a detailed programming approach, a simple empirical estimation is reported in order to verify the existence of negative externalities caused by farm abandonment. A logistic regression model is estimated for explaining the current land use x^* (1 : rice cropping, 0 : unused) by plot characteristics of and geographic proximities to the abandoned farms. The result shown in Table 4 is appropriate with a hitting ratio of 77. 6 %. Negative effects on continuing rice cropping is caused not only by low labor productivity and poor irrigation availability but also by proximity to the abandoned farms (within a range of 25 m). Figure 2 illustrates the probability of continuing rice cropping in each plot. Plots adjacent to abandoned farms are 20 to 30% more likely to remain unused. Needless to say, in the case of fluctuating prices or labor scarcity, this result is not considered meaningful.

(2) Calculating negative externalities with a programming model (Step 1)

The programming model (Step 1) is started from reproducing the baseline situation. The total regional labor input, $wmax^*$, is calculated based on equation (7) as 400 hours, which comprises 377. 6 hours of harvesting and 22. 3 hours of traveling between parcels. d_{hi} is assessed in the following three cases, 20 m, 25 m, and 30 m from plot i. c is parametrically changed by 0. 02 thousand JPY/a. Since the model includes integer variables, the result would not appear as a smooth curve line.

Figure 3 shows the result of the calculations in relation to changing externalities and the

Table 3. Plot-based coefficients in the model

Coefficients	Unit	Source
Plot area a_i	10 a	Calculation by GIS data based on orthorectified aerial photographs
Current land use x^*	1 : rice crop 0 : unused	Aerial photographs from 1976 and 2000 supported by the author's field survey in 2003
Parcel zo_i	1 : within 0 : outside of	Interview and field survey conducted in 2003
Proximity d	1 : consecutive 0 : not consecutive	Plots within a 20 m, 25 m, and 30 m radius are distinguished with GIS.
Profit coefficient r	1,000 JPY/10 a	$r = Y \cdot P - V$ Y : yield (kg/10 a), P : output price (1,000 JPY/kg), V : variable cost (1,000 JPY/kg) $Y = 134319 + 1047 \cdot LAT - 1288 \cdot LNG - 1.1 \cdot ILL$ LAT : latitude, LNG : longitude, ILL : rain-fed irrigation (rain-fed : 1) ($n=36$, $R^2=0.40$) $P = 0.267$, $V = 28.565$ (Rice production cost, average of commercial farm household in Shimane Prefecture 2002 : Cost includes seed and seedlings ; fertilizers and manure ; agricultural chemicals ; light, heat, and power ; miscellaneous materials ; and taxes, public imposts, and obligations)
Technical coefficient for harvesting labor w	hour/10 a	$w = \{(1-PF) \cdot Ts + PF \cdot Tf\}/a$ $Ts = (12.8\alpha\beta + 0.01\alpha + 0.00187 \cdot 2(\alpha+\beta) + 0.0255)/3600$ $Tf = (289\alpha\beta + 0.01\alpha + 0.00187 \cdot 2(\alpha+\beta) + 0.0255)/3600$ PF : probabilities of rice lodging Ts : Normal harvesting labor input, Tf : harvesting labor input for lodged rice (hour), a : area of plot (10 a), α : short-side length of the plot (m), β : long side length (m) $PF = 1/[1+\exp\{-(14.5 + 1.6 \cdot PM + 2.21 \cdot SOL)\}]$ PM : probability of inappropriate fertility management (rain-fed irrigation is 0.53, and irrigation ditch is 0.35), SOL : July solar radiation (Mj/m^2 $\cdot$ day)

affected distances. The hitting ratio in this model is maximized to approximately 76%, which is considerably close to the logistic regression result, as the unit c value ranges from 0.54 to 0.72 ; further, the distance considered is 25 m rather than 20 m or 30 m. Then, we assume that c would be the median value of 0.63 thousand JPY/a. [6] The sensitivity analysis of the impact of a yield variance is conducted based on the standard deviation of the estimated yield (6.18 from Table 3). A 1,000-time iterative calculation yields a 99% confidence interval for the total agricultural income π of 1.3 million JPY$\pm$ 0.68 thousand JPY and an unchanged hitting ratio.

The result of this calculation reveals that if

Table 4. Logistic regression results for the factors effecting the changes in land-use

Variables	Unit	Coefficients
Harvesting labor input requirement	hour/10 a	−0.59**
Irrigation (dummy)	rain-fed : 1, irrigation ditch : 0	−1.61**
Adjacent land use (dummy)	abandoned farms : 1, rice cropping : 0	−1.39**
Intercept	—	4.19**

Note: **indicates significance at the 1% level. The hitting ratio is 77.6%.

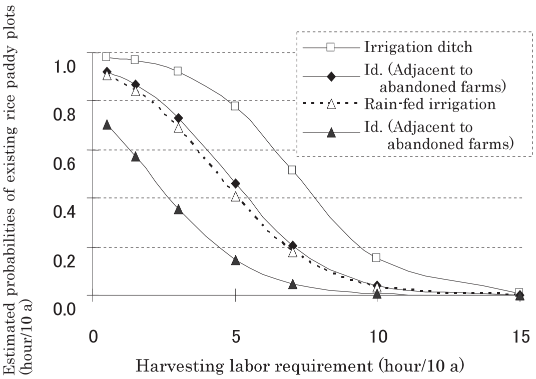

Figure 2. Estimated probability of continuing rice cropping in the case of each plot

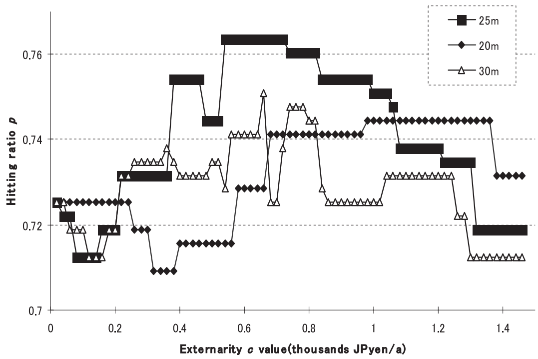

Figure 3. Hitting ratio with corresponding *c* value

Note: $d_{hi}=1$ for plots h, which are within a 20 m, 25 m, or 30 m radius of plot i.

there is a rice paddy adjacent to an unused (abandoned farm) plot within a 25 m radius, a cost of around 6,300 JPY per 10 a was incurred on the cropped area. This cost is equal to about one-fourth to one-third of the total variable costs. We can verify the reliability of this figure in a complementary manner. Through an interview survey of different villages, we found several points of practical evidence. For example, in one village close to the study area, farmers incurred costs of spraying operations on unused farmlands. Each operation cost 2,000 JPY/10 a, and it is preferable to spray the fields twice. Further, farmers in another village carried out weeding operations on behalf of the land owners of land that was left unused for an extended duration ; for this, the farmers received 11,250 JPY per 10 a in wages.

Figure 4 illustrates the location of wrongly classified plots in the case of $c=0.63$ and $d_{hi}=1$, for plots within a 25 m radius. Plots in black refer to those that were incorrectly optimized for cropping despite their current unused condition. On the other hand, plots drawn in white represent those that are current cropping ones optimized as unused. Such a mismatch is considered to be the effect of farmers' decisions based on individual circumstances.

3) Future land use plan based on changing situations (Step 2)

From the previous step, the following unknown coefficients are calculated : $c=0.63$ and $d_{hi}=1$ for plots within a 25 m radius. In the next step (Step 2), all the current plots ($x^*=1$), 11.6 ha of 198 plots, are considered in a future land use plan. Table 5 summarizes the result of the calculations for the different levels of labor scarcity, *wmax*, and negative externalities c. The baseline gross margin is calculated as 12.49 million JPY with a loss of 90,000 JPY caused by negative externality. Even if the labor input is 200 hours (half of

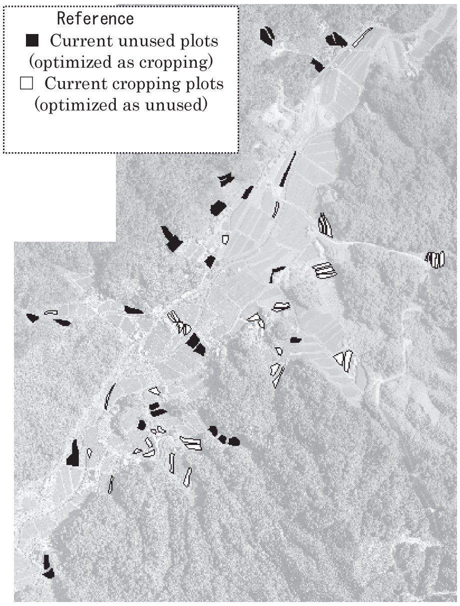

Figure 4. Location of incorrectly classified plots

the baseline), 6.6 ha of farmland is conserved and 7.17 million JPY of gross margin is maintained due to the fact that this result is optimized for income maximization. In the case of $c=0$, without considering externalities, the income figure becomes larger than in the case with externalities. However, plot area under the effect of externalities, E, would also increase. Hence, if the land use is decided upon by such criteria and there actuarially exist externalities of $c=0.63$, the total gross margin, for instance in the case of 300 hours of labor input, is reduced by 0.26 million JPY (4.1 ha×0.63 thousand JPY) to 10.35 million JPY.

Finally, a map of the future land use plan in a changing situation has been drawn with the help of the information calculated through the model. Obviously, the lower the labor input, the less the farmland is conserved. Figure 5 illustrates the cases in which $c=0.63$ and $c=0$ at given labor input levels (400, 300, and 200 hours). Both plans choose to continue farming in the consolidated plots located in the central area. In the case of the image on the left-hand side, ($c=0.63$), the plots of farmland in the suggested land-use plan are not scattered spatially when reflecting the affects of externalities as compared to the image on the right-hand side ($c=0$). This result supports the importance of an appropriate externality evaluation.

4. Concluding Comments

In this research, a linear programming model is constructed that can deal with unknown values of negative externalities caused by adjacent abandoned farmlands. First, a linear programming model is optimized in order to calibrate the unknown value of the unit cost of externalities. Here, the observed land-use pattern is taken as a hitting ratio criterion. As a result, the unit cost of the externalities caused by farm abandonment is calculated to be approximately 6,300 yen/10 a. This result can reproduce the observed land-use pattern at a hitting ratio of approximately 76%. Our method assumes that the

Table 5. The result of the LP model (Step 2)

Negative externalities c	Labor input in harvesting season $wmax$ (hour)	Area of rice paddy field $\Sigma a \cdot X$ (ha)	Regional total gross margin π (million JPY)	Area effected by negative externalities ΣE (ha)	Total loss caused by externalities $\Sigma c \cdot E$ (million JPY)	Labor input for moving to parcels $\Sigma m \cdot M$ (hour)
$c = 0.63$ 1)	400	11.6	12.49	1.2	0.09	23
	300	9.4	10.15	1.4	0.10	16
	200	6.6	7.17	1.5	0.11	10
$c = 0$ 2)	400	11.6	12.59	1.7	—	23
	300	9.5	10.35	4.1	—	16
	200	6.7	7.36	3.7	—	10

Note: 1) $c=0.63$ and $d_{hi}=1$ within a 25 m radius from plot i.
2) $c=0$ and the distance considered is 25 m. Although $c=0$, E can be calculated.

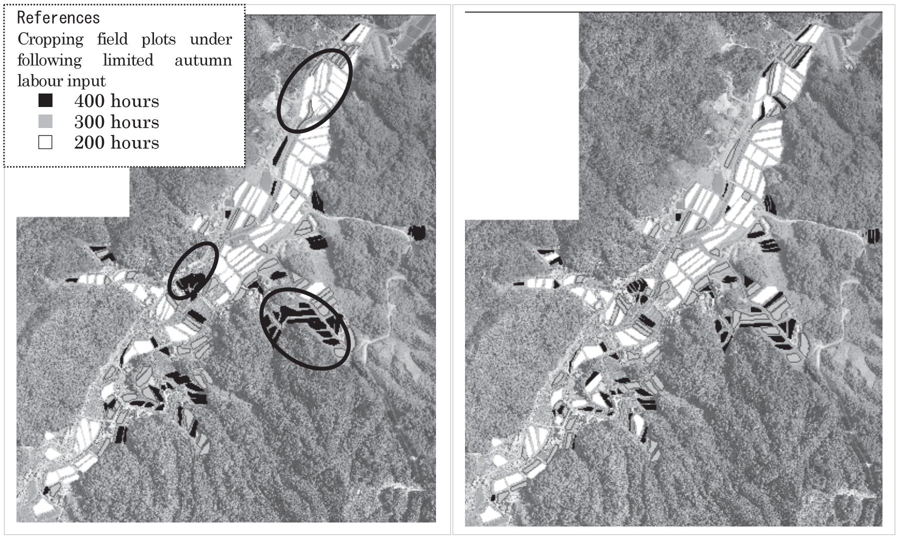

Figure 5. Land-use plan in the case of c=0.63 (left) and c=0 (the right-hand side depicts the case without considering externalities)

observed land-use pattern is derived from the result of farmers' income maximization behavior. Accordingly, it cannot be applicable to farmlands located on the urban fringe where land owners are likely to keep their lands for future development.

1) The National Chamber of Agriculture in Japan conducted a nationwide questionnaire survey in 1998 to investigate the reason for farm abandonment. The main reasons among multiple answers in the hilly and mountainous areas was aging and lack of labor resource, which accounted for over 80% of the total respondents. On the other hand, only about one in ten respondents chose discontinuing with farming as the reason.
2) We follow Yagi et al. [17] for the LP model.
3) The advantage of using data on labor in autumn instead of spring is that autumn being the busiest season, information on the achieved yield would be available concurrently with labor input data.
4) Mr. Hideki Ueyama of the National Agricultural Research Center for the Western Region provided the 50-meter-mesh solar radiation data. Solar radiation in June is considered the most significant period for the lodging of rice.
5) The GIS polygon generally stores the geographical location at the center of each figure, i. e., the field plot. Hence, the distances from the central point are automatically calculated. Three distances from each side—20 m, 25 m, and 30 m—are chosen, because the wider we set this range, the more varied effects other than externalities.
6) The calculation is conducted with an LP solver (with a non-linear and an integer option) created by Lindo Systems Inc.

References

[1] Endo, K. "Development of a Land Use Classification Method, Which Aims Distinguish Agricultural Land to be Conserved on Residents' Determinations in Hilly and Mountainous Area," *Transactions of Rural Planning*, Vol. 1, 1999, pp. 283-288.
[2] Folland, S. and R. Hough. "Externalities of Nuclear Power Plants: Further Evidence," *Journal of Regional Science*, Vol. 40, No. 4, 2000, pp. 735-753.
[3] Hayashi, K. "Mathematical Programming for Modeling Agriculture and the Environment," *Systems, Control and Information*, Vol. 47, No. 6, 2003, pp. 259-264.
[4] Hirano, N. "Kanto-Tozan-Tokai Chiiki ni okeru Suiden Ryudoka Shuseki no Tokucho," *Kanto Tokai Journal of Farm Management*, Vol. 90, 1999, pp. 53-56.
[5] Howitt, E. R. "Positive Mathematical Programming," *American Journal of Agricultural Economics*, Vol. 77, 1995, pp. 329-342.
[6] Kashiwagi, M. *Theories and Policies for the Regeneration of LFAs: A Comparative Study of the United Kingdom and Japan*, Tokyo: Association of Agriculture and Forestry Statistics, 2002.

[7] Kimura, K. "Sankan kyukeisya Suiden no Kohaika to Hojoseibi," in S. Nakagawa, ed., *Kosaku Hoki Suiden no Jittai to Taisaku*, Tokyo : Japanese Association of Agricultural Engineering Enterprises, 1993, pp. 51-74.

[8] Morita, H., S. Kobayashi and K. Morishita. "A Study on the Spatial Structure of the Residential Land Development in Kagawa Prefecture," *Journal of Rural Planning Association*, Vol. 22, SI, 2003, pp. 121-126.

[9] Moxey, A. P. "Efficient Compliance with Agricultural Nitrate Pollution Standards," *Journal of Agricultural Economics*, Vol. 45, No. 1, 1994, pp. 27-37.

[10] Preckel, V. P., D. Harrington and R. Dubman. "Primal/dual Positive Math Programming : Illustrated through an Evaluation of the Impacts of Market Resistance of Genetically Modified Grains," *American Journal of Agricultural Economics*, Vol. 84, No. 3, 2002, pp. 679-690.

[11] Sakuno, H. "Chusankan Chiiki ni okeru Kosaku Hokichi no Bunpu to Hassei Yoin," *The Study Meeting of the Association of Japanese Geographers Autumn* 2004, 2004, p. 145.

[12] Senda, T. "A Quantitative Analysis of Abandoned Cultivated Land in Japan," *Japanese Journal of Farm Management*, Vol. 36, No. 1, 1998, pp. 57-62.

[13] Tsuchida, S. "Method of Evaluating Paddy Field from the Viewpoint of Farm Management," *Hokuriku National Agricultural Experiment Station Agricultural Economics Report*, Vol. 43, 1994, pp. 1-29.

[14] Tsuruoka, Y. "Farmland Condition Effects on Farmland Size Enlargement and Profitability under Productive Management Conditions," *Japanese Journal of Farm Management*, Vol. 39, No. 1, 2001, pp. 1-13.

[15] Yagi, H. "Clarification and Prediction of the Negative Externalities on Farm Activities from Non-farm Lang Use," *Journal of Rural Planning Association*, Vol. 22, 2003, pp. 79-84.

[16] Yagi, H., K. Ohro, Y. Yamashita and H. Ueyama. "An Estimation of Land Parcel Information for the Economical Land Classification in Marginal Areas," *Proceedings of Annual Conference of the Agricultural Economics Society of Japan*, 2003, pp. 120-122.

[17] Yagi, H., Y. Yamashita, K. Ohro and H. Ueyama. "Income-Based Land Classification of Field Plots for Disadvantaged Areas: A Study Considering Negative Externality of Farmland Abandonment," *Journal of Rural Planning Association*, Vol. 23, No. 2, 2004, pp. 137-148.

[18] Yagi, H. "Senkeikeikakuhou no Jissyoutekitekiyou niyoru Nouchiriyoukeikaku (An Empirical Application of the Linear Programming Model for Agricultural Land Use Planning : Through the Valuation of Negative Externalities Caused by Farmland Abandonment in Marginal Areas)," *Nogyo Keizai Kenkyu* (*Journal of Rural Economics*), Vol. 78, 2006, pp. 12-21.

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