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Game Theory Analysis of Agricultural Land Fragmentation in Thailand

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ABSTRACT

Agricultural land fragmentation (ALF) is a common issue in rural areas in developing countries, impacting agricultural productivity and future food security. Thailand is one of the countries having an ALF problem. To analyze this problem, we use a game theory model having two players: landowners (L) and the government (G). Landowners have two strategies: fragment (F) and non-fragment (N) while the government has two strategies: encouragement (E) and implementation of punishment (I). In this model, we determine four variables that affect the landowners' decision-making: the expected value of fragmented land (VF), the expected value of non-fragmented land (VN), the implement punishment value associated with land fragmentation (IV), and the encourage value of maintaining non-fragmented land (EV). We find that in an ideal model suggests landowners often choose N; however, real data indicates that landowners prefer F over N. We also determine all possibilities of the ALF problem. To address this problem, the government should increase IV and EV or decrease $VF - VN$, but both scenarios seem quite hard in Thailand.

Keywords: Agricultural land fragmentation; Game theory; Thailand

1. Introduction

Agricultural land fragmentation (ALF) is the process of breaking larger areas of farmland into smaller pieces. In 2021 [1], ALF can be caused by various political, social, biological, and environmental factors such as inheritance, population increase, urbanization and development, land use planning, zoning policies, informal land ownership, land use changes, and large-scale purchases. ALF has many effects such as leading to difficulties in land management, increased production costs, and decreased agricultural productivity. Given the population growth projected globally, food production must increase by 70% by 2050, as reported by [2]. As a result, the ALF problem has negative impacts on food production and can contribute to food insecurity in the

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future. This implies that decision-makers must implement necessary reforms, such as sustainable land management, to raise agriculture and increase agricultural efficiency. For more information about ALF, see [3-6].

In many countries, especially in developing countries, ALF can have a significant impact on agricultural production, crop yields, production costs, and farm productivity. It can also lead to a reduction in the land area available to farming households, potentially affecting food security and rural development. ALF not only increases the labor supply but also reduces the overall efficiency of farming activities. For example, in Iran, ALF has negative effects on agricultural production, crop yields, production costs, and farm productivity. It has also resulted in a reduction of available land area for farming households. The average land area of each farming household decreased by about 1.2 hectares from 1989 to 2015 [7]. In [8], Janus and Markuszewskab found that in Poland, ALF is harmful to agricultural productivity. The paper suggests that consolidating land can lead to the development of larger, more efficient farms, ultimately improving productivity. In [9], Tran and Vu found that in Vietnam, ALF affects farm production because a large labor force is often required to work on fragmented farms and more time is needed for travel between plots. Since machines can only work in large areas with regular shapes, this prevents farmers from using modern, mechanized equipment such as tractors. Additionally, it prevents the adoption of high-profit crops that can only be cultivated on a large scale.

In Thailand, as in many other developing countries, ALF can lead to higher production costs, less efficient farms, and reduced economies of scale. In [10], Menakanit found that road construction has fragmented the vegetable production areas in Thawi Watthana district, resulting in a decrease in their size and productivity. These changes can have economic and social impacts on farmers and communities that depend on these areas for their livelihoods. Additionally, ALF can lead to smaller and less efficient farms, reduced access to resources such as water and fertilizer, and increased vulnerability to pests and diseases. According to the report [11] by the Office of Agricultural Economics (OAE), farms in rural Thailand have become smaller and more divided. In 2019, households in these areas typically had four farm parcels, with each household owning about 3.9 hectares on average. Currently, each household manages an average of approximately 3.6 hectares even though each household still has four farm parcels. Furthermore, in [12], S. Chomchan and K. Nopparat identified several significant causes of ALF: a) Aging farmers who have no heirs to take over farming. This increases the chance of ALF, which is considered the primary concern. b) Some landowners choose to sell their land and deposit the proceeds in banks, where the interest income is higher than in agriculture. c) Landowners who also farm face challenges in their agricultural livelihood due to uncertainties in agricultural product prices and crop damage from flooding, leading to indebtedness. Consequently, they consider selling their land to change their occupation. Additionally, while the overall concept of preserving agricultural lands is specific, there is a lack of continuity in the processes or policies. The risk of crop losses as a result of climate change also increases the opportunity to sell land for agriculture. At present, the government has implemented two primary sets of policies to manage changes in ALF: a) Encouraging land consolidation and conservation through policies such as tax breaks, financial support for land improvement, and the construction of irrigation systems. b) Implementing punishment measures, such as withholding support for small and fragmented farms owned by non-farmers and not granting

ownership rights to divided and abandoned land. Although policies are in place to prevent it, why does the problem of ALF persist, and why do agricultural lands continue to fragment? This study aims to answer these questions using Game Theory.

2. Game Theory Model

In this section, we use game theory to analyze the ALF problem. The game model for ALF in Thailand includes the following three components:

a) Set of players: Considering those directly involved in the benefits, there are two parties, which are landowners and the government. In this model, there are two players: landowners (Player L) and the government (Player G).

b) Strategy set of players: For the landowners, player L has two actions: fragmenting or not fragmenting the land. Then we let the strategies of player L be Fragment (F) and Non-fragment (N). On the government side, they reward landowners who keep their land undivided, while they punish landowners for dividing their land. As a result, player G adopts the strategies of Encouragement (E) and Implementation of punishment (I).

c) Preferences of the players: The preference of each player depends on his/her payoffs under each strategic position of the model. This model has four main positions: *FI*, *FE*, *NI*, and *NE*. The notations of payoffs for the players are shown in Fig. 1.

Players		G	
	Strategies	I	E
L	F	$(P_L[FI], P_G[FI])$	$(P_L[EI], P_G[EI])$
	N	$(P_L[NI], P_G[NI])$	$(P_L[NE], P_G[NE])$

Fig. 1. The notations of payoffs for the players.

[11, 13-15] shows that rice is the most utilized crop in agricultural land use in Thailand, so we use real data from rice cultivation in our models to determine the structure of the ALF model. Firstly, we create a model to understand how players should behave optimally in the game model, called the "ideal model".

In Thailand, the size of the land has an impact on the socio-economic status of landowners, see [16]. Hence, if they do not have any financial difficulties, they prefer not to fragment their lands. Moreover, they prefer that the government does not punish them. Therefore, we assume that the landowner's order of preferences (P_L) for different situations in the ALF model is

$$P_L(NE) > P_L(NI) > P_L(FE) > P_L(FI)\,. \tag{2.1}$$

From the government's perspective, although the government is willing to support farmers in not dividing their land, if necessary, they can use punishment measures. Since farmers in Thailand are more likely to respond to punishment measures than to encouragement, we may assume that the government prefers to implement punishment measures over encouragement measures. Hence, the government's order of preferences in the ALF model is

$$P_G(NI) > P_G(NE) > P_G(FI) > P_G(FE)\,. \tag{2.2}$$

The movement diagram of the model satisfying Eqs. (2.1)-(2.2) is presented in Fig. 2. Hence, the only Nash equilibrium in this ideal model is *NI*. Moreover, this equilibrium is Pareto optimal, so this model is solvable in the strict sense. This means *NI* is acceptable as a solution for this model.

Players		G	
	Strategies	I	E
L	F	$(P_L[FI], P_G[FI])$	$(P_L[EI], P_G[EI])$
	N	$(P_L[NI], P_G[NI])$	$(P_L[NE], P_G[NE])$

Fig. 2. The movement diagram of the ideal model.

Next, we construct an ALF model from a real-life situation. In fact, farmers have more complex preferences that depend on various factors such as a) the expected value of fragmented land (*VF*) which is the value that farmers receive from selling scattered land, b) the expected value of non-fragmented land (*VN*) which is its current expected profit over the production life, c) the implement punishment value associated with land fragmentation (*IV*) which is considered from the following concept. When farmers sell some of their land, the government must import rice equivalent to the amount that can be produced in the lost area. Hence, we assume that *IV* is equal to the cost of importing that amount of rice, and d) the encourage value of maintaining non-fragmented land (*EV*) which is determined by multiplying the government support by the amount of land held. [17] showed that the government support rice farmers by providing 1 thousand Thai Baht per rai. Thus, the expected payoffs for the players are as follows:

a) The expected payoff of player *L* at the *FI* position ($P_L[FI]$) is calculated by $P_L[FI] = VF - IV$. Similarly, player *G*'s expected payoff for this position $P_G[FI]$ is determined by the value that player obtains from *IV*.

b) The expected payoff for player *L* at the *FE* position is determined by the value that landowners receive from *VF*. In the case of player *G*, when landowners choose to divide their land, the government does not provide financial support. Then $P_G[FE] = 0$.

c) The expected payoff for player *L* at the *NI* position is determined by *VN*. For player *G*, landowners choose not to divide their land, which means the government does not need to impose a punishment. Then $P_G[NI] = 0$.

d) The expected payoff of player *L* at the *NE* position is calculated by $P_L[NE] = VN + EV$. On the other hand, for player *G*, landowners choose not to divide their land, leading the government to provide financial support. Then $P_G[NE] = -EV$.

To summarize, the resulting payoff matrix is shown in Fig. 3.

Players		*G*	
	Strategies	***I***	***E***
L	***F***	$(VF - IV, IV)$	$(VF, 0)$
	N	$(VN, 0)$	$(VN + EV, -EV)$

Fig. 3. The resulting payoffs for the players.

According to [11, 13-15, 17-18], the average net profit per rai of a rice farm is –0.19 thousand Thai Baht. ($c = -0.19$). Based on the fact that an individual can buy and sell land independently, they must be of legal age (at least 20 years old). According to the OAE report, the workforce extends up to 64 years old. Therefore, we assume that a farmer can engage in agriculture for approximately 44 years. Then we assume that the time cycle of the life span is 44 years ($t = 44$), and the Bank for Agriculture and Agricultural Cooperatives (BAAC) offers farmers an average deposit interest rate of 0.25% per year for depositing their agricultural income ($r = 0.0025$) where 1 rai = 0.16 hectares. The average rice yield in Thailand is approximately 0.47 tons per rai ($y = 0.47$), and the average cost paid by the government for importing one ton of rice is 17.57 thousand Thai Baht ($i = 17.57$). Moreover, each farmer has an average farm area of 22.5 rai ($a = 22.5$), and the government's financial support is 1 thousand Thai Baht per rai ($s = 1$). Then *VF, VN, IV,* and *EV* are as follows:

a) $VF = 52$ thousand Thai Baht,

b) $VN = c\,[(1 - (1 + r)^{-t})/r]$
$= -0.19[(1 - (1+0.0025)^{-44})/0.0025]$
$= -8.05$ thousand Thai Baht (it is the formula for the present value),

c) $IV = y \times i = 0.47 \times 17.57 = 8.26$ thousand Thai Baht (it is the cost to be paid by the government for importing rice), and

d) $EV = s \times a = 1 \times 22.5 = 22.5$ thousand Thai Baht.

The payoff matrix for this model is shown in Fig. 4.

Players		G	
	Strategies	*I*	*E*
L	*F*	(43.74 , 8.26)	(52 , 0)
	N	(-8.05 , 0)	(14.45 , -22.5)

Fig. 4. The real-life situation model.

Then *FI* is the unique equilibrium, which is different from one of the ideal model. In the next section, we construct a model of possibilities involving *VF* and *VN*, which affect the decision-making of landowners. We consider which situations Thailand is similar to and how we can adjust certain factors to solve the ALF problem.

3. Main Results

We already observe that, according to the ideal model, landowners choose non-fragmentation as the solution. However, in the real-life situation model, landowners choose to fragment their land. This raises the question: why does the ALF problem occur in Thailand? The reason for this issue may be that players in the game make decisions based on what is best for themselves individually rather than looking at the overall outcomes for the entire system. To address the ALF problem, we primarily consider from the perspective of the landowners that the variables that affect decision-making are *VF* and *VN*. To construct a model for analyzing all possibilities of the ALF problem, we begin by considering the following main situations based on the values of these two variables:

A) $VF = VN$

B) $VF < VN$

C) $VF > VN$

From Fig. 3, if the government wants to prevent ALF through a combination of punishment and encouragement policies, these policies must be highly effective. We suppose that Strategy *N* is a dominant strategy. Consequently, *VN* is greater than or equal to $VF - IV$, also $VN + EV$ is greater than or equal to *VF*, and at least one of them must be significantly higher.

In other words, the following inequalities hold:

$$IV \geq VF - VN, \tag{3.1}$$

and

$$EV \geq VF - VN, \tag{3.2}$$

At least one of Eqs. (3.1)-(3.2) must be strictly greater.

Under these conditions with *IV* and *EV* greater than zero, the payoffs for the players in the ALF model are shown in Figs. 5-8.

In Situation A), the movement diagram is shown in Fig. 5. Then *NI* is the unique Pareto optimal equilibrium. Hence, the government should use the punitive policy in this situation. Moreover, this model is solvable in the strict sense, so the resulting solution is acceptable.

Players		G	
	Strategies	*I*	*E*
L	*F*	$(VF - IV, IV)$	$(VF, 0)$
	N	$(VN, 0)$	$(VN + EV, -EV)$

Fig. 5. $VF = VN$.

In Situation B), when $VF < VN$, Strategy *NI* is the unique Pareto optimal equilibrium shown in Fig. 6. Similar to Situation A), the government should implement the punitive policy in this case.

Players		G	
	Strategies	*I*	*E*
L	*F*	$(VF - IV, IV)$	$(VF, 0)$
	N	$(VN, 0)$	$(VN + EV, -EV)$

Fig. 6. $VF < VN$.

In Situation C),

C1) $VF > VN$, $VN = VF - IV$, and $VN + EV > VF$.

Then *FI* and *NI* are equilibria shown in Fig. 7. However, these conditions may not be sufficient to motivate landowners to choose Strategy *N*.

C2) $VF > VN$, $VN > VF - IV$, and $VN + EV \geq VF$.

Then *NI* is the unique equilibrium shown in Fig. 8, which is a preferable solution.

To sum up, the government should apply only the punitive policy in case C. Moreover, if *IV* is large enough ($IV > VF - VN$), it is sufficient to motivate landowners to choose Strategy *N*.

Players		G	
	Strategies	*I*	*E*
L	*F*	$(VF - IV, IV)$	$(VF, 0)$
	N	$(VN, 0)$	$(VN + EV, -EV)$

Fig. 7. $VF > VN$, $VN = VF - IV$, and $VN + EV > VF$.

Players		G	
	Strategies	*I*	*E*
L	*F*	$(VF - IV, IV)$	$(VF, 0)$
	N	$(VN, 0)$	$(VN + EV, -EV)$

Fig. 8. $VF > VN$, $VN > VF - IV$, and $VN + EV \geq VF$.

According to the situation of rice cultivation in Thailand provided in Section 2, we have $IV = 8.26$, $EV = 22.5$, and $VF - VN = 60.05$. Then Thailand falls into case C. To solve the issue of ALF in Thailand, we may need to adjust some variables to satisfy Situation C2. This means $IV > VF - VN$, and $EV \geq VF - VN$. Thus, the government may need to increase *IV* to be greater than $VF - VN$ and increase *EV* to be at least $VF - VN$. This implies that the government must change the implemented punishment value associated with land fragmentation from 8.26 to be greater than 60.05. This action might be considered too harsh and cruel by the Thai people, potentially leading to discontent and the possibility of protests. Additionally, the government needs to increase the encouragement value of maintaining non-fragmented land from 22.5 to be greater than or equal to 60.05. Considering the budget allocation to support it, the budget is a huge amount, making it a difficult choice.

On the other hand, the government may solve this problem by decreasing $VF - VN$ to be less than *IV* and $VF - VN$ to be less than or equal to *EV*. We have that $VF - VN$ involves various variables, including agricultural land prices (*Lp*), agricultural product prices (*Pp*), and agricultural product costs (*Pc*). To decrease $VF - VN$, we need to reduce *Lp* (to decrease *VF*), decrease *Pc* (to increase *VN*), and increase *Pp* (to increase *VN*).

The trends of land price, product price, and product cost from 2012 to 2021 are shown in Fig. 9. When we consider all the values, we find that it is quite hard to reduce $VF - VN$ to be less than *IV* and to be less than or equal to *EV*. For instance, in 2021, $Lp = 325$, $Pp = 8.31$, and $Pc = 9.56$. Then $VF_{2021} = Lp = 325$, $VN_{2021} = c\,[(1 - (1 + r)^{-t})/r] = (Pp_{2021} - Pc_{2021})[(1 - (1 + r)^{-t})/r] = -52.02$, so $VF_{2021} - VN_{2021} = 377.02$ and $IV_{2021} = 6.31$. Consequently, there is a widening difference between *VF* and *VN*, and this gap expands each year.

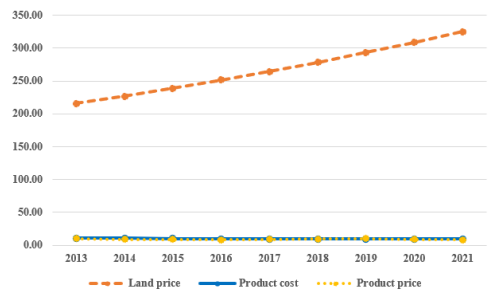

Fig. 9. The trends of land price, product cost, and product price over 2012–2021.

4. Conclusion

We consider the ALF problem situation occurring in Thailand, using a game theory model based on data from rice cultivation as a model. The ideal model shows that ALF should not occur in Thailand; however, in reality, landowners often opt for fragmentation. In this study, we find that whether the government aims to increase the implement punishment value, raise the encourage value, or decrease the difference between the expected value of fragmented land and the expected value of non-fragmented land, all of these seem difficult in Thailand. Consequently, the issue of ALF persists.

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