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Agricultural land fragmentation in Iran: Application of game theory

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ABSTRACT

Agricultural land fragmentation (ALF) is one of the main challenges of developing countries including Iran. ALF could affect agricultural production, rural development, labor supply, food security, and land use change. Therefore, ALF management should be one of the main components of the land policy and decision-making systems regarding agricultural lands. In Iran (similar to many other countries), ALF has two main players: farmers and government. The main aim of this study is to explain and evaluate the strategic space of decision-making between farmer and government regarding the issue of ALF in Iran using game theory. It presents an ALF strategic game model based on the ordinal and cardinal preferences of the players. The results of this study show that, in the ordinal form of the game, the farmer tends to fragment his or her agricultural land, although the strictly dominant strategy of the farmer is "do not fragment". The main causes of conflict include: a) The players of this game act with respect to their best individual response and without considering the whole system payoffs; b) The players cannot create the necessary structures for collaboration; and c) There is not an external authority to enforce rules and regulations of the game. This study analyzes the ALF game under cardinal preferences that is closer to the real world of ALF. Concerning cardinal preferences, the best response of each player is related to at least four variables: the value of fragmented land (VF) and non-fragmented land (VN), the punishment value (PV), and the encouragement value (EV). This study concludes that if a government or land policy-makers want to manage ALF, they should not apply the same strategies for all the agricultural lands. The proper strategy for any kind of land is not only dependent on their policies (PV and EV) but also on VF and VN.

1. Introduction

Agricultural land fragmentation (ALF) is a phenomenon observed in many countries, especially in the developing ones (Veljanoska, 2018) including Iran (Abdollahzadeh et al., 2012). There are many socio-economic, political, ecological and environmental reasons leading to ALF such as population growth, the inheritance system, increase in land prices, road network and urban expansion, disasters, climate changes, family size and income, etc. (Asadi et al., 2016; Gomes et al., 2019; Kalantari and Abdollahzadeh, 2008; Mesgaran et al., 2016; Niroula and Thapa, 2005). ALF has many outputs and impacts. For example, it has not only affected agricultural production, crop yields (Veljanoska, 2018), production costs (Gonzalez et al., 2007; McDonnel, 2018), farm productivity (Looga et al., 2018), the potential income of farms (Janus et al., 2016), and land loss (Lam et al., 2018) in a negative way but also had a significant positive impact on agricultural production diversification (Ciaian et al., 2018) and non-agricultural labor supply (Xie and Lu, 2017). Nevertheless, in many countries across the world ALF is associated with lower agricultural production and, more broadly, limited rural development (Jürgenson, 2016). With respect to the rising demographic changes in the world, it is expected that the world needs 70 % more food production (by 2050). It means that policy-makers need to make necessary reforms for agricultural transformation and efficiency such as sustainable land management (FAO, 2011). Management of fragmented lands is one of the main dimensions of sustainable land management. McPherson (1982) defined land fragmentation as a number of spatially separated parcels of owned or rented farming lands. ALF is also defined as the position in which a single farm consists of many parcels separated by space (Demetriou, 2014). Usually, when farmland is divided into numerous parcels, which are usually small but not in good shape, its production costs will be increased, and it will reduce the potential income of cultivation (Jürgenson, 2016). ALF not only increases the production costs to farmers but also has some negative impacts upon land use including land abandonment and land market

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depression, when land parcels are very small and highly fragmented (FAO, 2007).

According to the Statistical Center of Iran (2017), the average farm area of each farmer household in 1989–2015 ha s decreased from about 6 ha to about 4.9 ha. The main problems associated with land fragmentation include a) managing the land parcels, i.e., the number of pieces and lack of access (due to the distance between them and the farmstead) considered as the main causes; b) increasing the unutilized lands due to the expansion of the border lines between parcels; c) decreasing productivity due to small size and irregular shape of parcels (Abdollahzadeh et al., 2012); and d) increasing the probability of agricultural land conversion (Azadi and Barati, 2013; Azadi et al., 2011; Barati et al., 2015). It could also be added to farm costs and reduce operational efficiency with extra machinery, labor, travel time, facilities, and crossing roadways (McDonnel, 2018).

In addition, land ownership in Iran, such as many other countries, is still one of the major sources of wealth and livelihood. Land is one of the two main central requirements of agriculture and rural development (another one is water). It is also inherently associated with other global challenges, such as food security and poverty, adaptation and mitigation of climate change, as well as the natural resources' degradation and depletion. These challenges have affected the livelihoods of millions of rural (FAO, 2011) and urban people across the world. Therefore, to improve the policies and the decision-making procedure about agricultural lands management and governance, it is very important to understand and to explain the structure of ALF happening. This paper aims to explain the structure of the ALF phenomenon using game theory. The obtained results not only help policy-makers to realize the strategic structure of farmers' decision-making but also to identify their best responses to different strategic situations. Therefore, the main contribution of this study is to present the application of game theory to understand the structure and the strategic situation of the ALF issue. In this regard, this study also aims to find answers for these main questions: 1) Is game theory useful for the analysis of land issues such as ALF? 2) What is the structure of ALF as a strategic game (players, players' actions, and players' payoffs)? 3) What are the different strategic situations of ALF as a strategic game? and finally, 4) What is the best action of each player (government or farmer) against the other player's actions?

The structure of this paper is as follows. Section 2 introduces game theory and its advantages and limitations applied to land policy and management. Section 3 discusses the methodology of the paper. In this section, the kind of game, why and how it is used, the structure of the game, and how it actually works are explained. Section 4 is about the study area (ALF in Iran). The structure of the game according to Iran's situation is explained there. In Section 5, the results of the game model are presented. Finally, section 6 discusses and concludes the usefulness of game theory for decision and policy-making processes and offers some suggestions for further studies.

1.1. Elements of game theory

Game theory (GT) is intended to help scientists to comprehend circumstances in which decision-makers (players) interact in an interdependent situation called the "game." GT is part of decision-making theory which usually analyzes decision-making processes from a single player's point of view, and involves multiple decision-makers with competing, often contradictory preferences (Myerson, 1991; Samsura et al., 2010) according to a set of rules (Osborne, 2004). Since GT can be used to anticipate how people follow their own interests against or together with the interests and preferences of others, GT has been used for the study of conflict and collaboration between rational decision-makers (Avenhaus, 2009; Myerson, 1991; Rapoport, 2012). In a typical game, each player aims to maximize his/her payoffs by anticipating the decisions (plays) of the other(s) which results in multi-criteria problems that could not be solved by conventional optimization methods but requires taking the objectives of others into consideration (Avenhaus, 2009; Madani, 2010).

Although mathematicians and economists contributed most to GT, it has also greatly impacted other areas in the social sciences, physics, biology and computer science. Rationality and intelligence are two basic statements that are generally made by game theorists about players. Rationality means that players consistently pursue their own goals. In classical terms, each player seeks to enhance the expected value of his/her own payoff. It is also called rational choice theory, which is an element of many GT models. It means that a player selects the best action (play) according to his preferences from all available actions (plays) (Osborne, 2004). Intelligent means that a player knows everything the other players know about the game and is able to make any assumptions regarding the situation they might make (Myerson, 1991).

A game is described by its form (structure) which should be neither too simple to ignore vital aspects of the real world nor too complex to obscure our evaluation by distorting the basic issues. Various general forms are used to represent games, but the most vital ones are the extensive and strategic (or normal) forms. The strategic form is conceptually simple (Myerson, 1991) and useful for general analysis purposes. To investigate ALF, this paper uses the normal form of games.

There are at least three components in a strategic game including a) a set of players, b) a set of actions (for each player), and c) the preferences over the set of action profiles (for each player) (Osborne, 2004). One of the most important examples of the game theoretical models is the Prisoners' Dilemma (PD). This game is one of the most well-known strategic games and is used to derive important analytical principles of collective action problems (Bilancini and Boncinelli, 2018; Bredewold and Veenema, 2018; Ostrom, 2000; Samsura et al., 2010; Straffin, 1993). In the classical PD game, two suspects are placed in separate cells in a major crime. They will be convicted of a minor crime and spend a year in prison if they both remain silent (do not confess). If only one confesses, he will be released, and the other will be imprisoned for three years. Everyone will spend two years in prison if they both confess. This can be modeled with the following components as a strategic game:

a) A set of players: [suspect A, suspect B].
b) A set of each player's actions: [Confess, Don't Confess].
c) Preferences of the players: suspects' ordering of the action profiles, from the best to the worst.

Fig. 1 represents the strategic form of the PD game. The cells' values show the payoffs of each player (based on the number of years each prisoner should be in prison). The left value in each cell is the payoff of player A, and the right value is the payoff of player B (the numbers in parentheses include the years in which a person should be in prison in each situation, and the values without parentheses are the preference orderings from 1 to 4).

The A's and B's preference orderings are as follows:

$$u_A\ (C,\ D) > u_A\ (D,\ D) > u_A\ (C,\ C) > u_A\ (D,\ C)$$

Players		B	
	Actions	Don't Confess (D)	Confess (C)
A	Don't Confess (D)	2 , 2 (1 , 1)	4 , 1 (3 , 0)
	Confess (C)	1 , 4 (0 , 3)	3 , 3 (2 , 2)

Fig. 1. The Prisoner's Dilemma strategic game: example of the payoff matrix. Brackets numbers indicate the number of years in prison (1 is first preference and 4 is fourth preference).

$u_B (D, C) > u_B (D, D) > u_B (C, C) > u_B (C, D)$

The PD game implies that there are gains from collaboration, thus both players prefer to jointly choose (D, D) rather than (C, C). This game is vital because many other real-world situations have similar features, such as ALF which includes a situation involving cooperative behavior in which both players could benefit significantly from cooperation or suffer from non-cooperation). After defining a game, it can be used to evaluate and explain the situation (solving the game) which means to find the right move or the best action of each player or the whole system in which the players or the system will reach their optimal goals (their best payoff). While there are many solution concepts for each game, the most common is the Nash Equilibrium (NE) (Fudenberg and Tirole, 1991) in which no player could gain anything by changing only the own strategy. Based on this definition, the PD has a single NE in which both players choose to confess (C, C) (Fig. 1). In other words, NE is an action profile $\alpha^* = (a_i^*, a_{-i}^*)$ with the property that no player i can do better by selecting an action other than α_i^* (a_{-i}^*), given that every other player j adheres to α_j^* (Eq. 1) (Osborne, 2004).

$$u_i(a^*) \geq u_i(a_i, a_{-i}^*) \text{ for every action } a_i \text{ of player i} \quad (1)$$

where u_i is a payoff function that represents player i's preferences. Every player has a strictly dominant (SD) strategy in the PD game, giving this player a strictly higher payoff regardless of the actions of any other player (Avenhaus, 2009; Gibbons, 1992; Myerson, 1991; Osborne, 2004; Straffin, 1993).

Another important concept of the GT is the Pareto optimal equilibrium (POE). NE does not generally correspond to a socially beneficial result. A POE discusses a social optimum in which by enhancing one player's payoff, at least one other player would be harmed (Vriend, 2000). Often, an NE might not be a POE implying that the players' payoffs can all be increased and vice versa (Madani, 2010). While a POE is not a solution principle, it can be an essential feature in evaluating what players should play or learn to play over time. All strategies of the PD game are POE: (D, D) is Pareto optimal because there is no profile that gives both players a higher payoff, (C, D) is Pareto optimal because there is no profile that gives player A a higher payoff, and so are (D, C) and (C, C). In PD games, however, the SD strategy for each player is to confess (C), which means that it is always better to confess (it is because, in CD situation 0 year in prison is better than 1 year, and in CC situation 2 years in prison is better that 3 years), regardless of whether the other player chooses to confess or not. Therefore, for both players, the outcome (C, C) which is also an NE and has lower payoffs compared with the optimal Pareto (D, C) and (D, C), is the SD strategy. It is also the most likely solution of the game under the game conditions (the most important solution when there is no communication).

1.2. Role of game theory in land fragmentation

Land is a vital factor for wealth in agriculture and rural development. In addition, it is inherently linked to main global challenges such as food insecurity, poverty, climate change, and natural resources degradation and depletion that affect the livelihoods of millions of people across the world (FAO, 2011) including Iran (Dehghani Pour et al., 2017). However, it is a common and critical property for humankind and a strategic property for rural people that increases their social and economic status in society. Therefore, there is increasing competition for land. In Iran's rural areas, the status of people and their livelihood are highly intertwined with land use (Barati et al., 2015) and other environmental resources. It has led to severe degradation of environment, land, and soil (Dehghani Pour et al., 2018; Eghdami et al., 2019). These situations often make it impossible for decision-makers to choose a suitable alternative from a set of land management actions. In particular, the implementation of any given alternative affects stakeholders with different world views, values, and interests (Shields et al., 1999). It makes the land issues and their management more complex. Consequently, it implies that the management of land issues not only needs to consider its cooperation and competition aspects but also requires paying attention to its complexity. The GT is the formal tool to study the conflict and cooperation situations (Gibbons, 1992; Myerson, 1991), and it is also a proper analytical tool for complex situations. Additionally, the ALF is one of the main components of any agricultural land management and policies, taking cooperation, conflict and complex situations into consideration. It has been a common feature of many countries without a developed agricultural system (Dhakal and Khanal, 2018). The multiplicity, variety, and existence of interrelation among the causes of land fragmentation have made it a complex issue. For example, inheritance, poverty, raising population, land markets, environmental changes, natural disasters such as drought and floods, regulations and rules, historical and cultural backgrounds, land reforms and distribution, etc. are some of the causes of land fragmentation in Iran and many other countries such as Nepal, Albania, India, and so on (Abdollahzadeh et al., 2012; Ciaian et al., 2018; Dhakal and Khanal, 2018; Jha et al., 2005). In addition, land fragmentation or making any decisions in this regard are strategic issues that will affect other farmers, people, and decision makers.

GT is a proper tool to investigate ALF, represented by a strategic situation in which one agent's behavior affects another agent's payoff or utility (Osborne, 2004). These agents may be individuals, groups, companies, organizations, or any of these combinations. With respect to agricultural land fragmentation processes, the GT was not applied to land except in few other related fields such as land transfer (Liu and Li, 2013), land-use spatial optimization (Liu et al., 2015), and land and property development (Samsura et al., 2010). In the following, the ALF situation is structured simply as strategic or normal forms of the games to raise our understanding of decision-making.

1.3. Agricultural land fragmentation in Iran

Like many developing countries, agricultural lands in Iran have been fragmented. Currently, the average number of farm parcels in rural areas is more than 5 per household. With regard to the average farm area of each farmer (about 4.9 ha in 2015) (Statistical Center of Iran, 2017), the mean area of each farm has shrunk to less than one hectare. Historically, the source of this issue has been pursued in Iran's land reform programs (1962–71). Land reform in Iran has benefited about 74 % of farmers, and 67 % of rural households (1.8 million tenant farmers) and radically changed land ownership patterns (Hooglund, 2012; Majd, 1987). The implemented policy by the government affected both the government and farmers. The land heritage law was the other major driver of land fragmentation in Iran (Abdollahzadeh et al., 2012; Kalantari and Abdollahzadeh, 2008). Based on Islamic inheritance law, their property (including lands) should be divided among all heirs after the landlord death. Since land ownership is a major source of socioeconomic status, no one refuses to stand up for his/her rights. Therefore, lands (including agricultural lands) have been severely fragmented. Unlike many studies, a few claimed that the various parcels of farms in Iranian agriculture are not primarily a product of Islamic inheritance laws. The reason for this practice is historically linked to topography and a distributive social structure (Ehsani, 2006). Raising the land price, because of the underdeveloped land market (Kalantari and Abdollahzadeh, 2008; Niroula and Thapa, 2005), is another important cause of agricultural land fragmentation. As land prices rise, some landlords encourage the supply side to divide their land and sell it to gain more profits. On the demand side, there are some investors who want to buy a parcel of land for investment purposes. Reducing the usefulness of agricultural activity is a more recent driver of agricultural land fragmentation.

Along with the decline in profits from agricultural activity, farmers are becoming poorer and persuaded to divide and sell their land to provide their families with livelihoods or migrate to urban areas. It will not only lead to conflict in urban areas but will also lead to a shortage of labor for agricultural activity, which is a major driver of declining agricultural profitability and more fragmentation, particularly by small farmers (Niroula and Thapa, 2005). Another important driver of agricultural land fragmentation in Iran is the lack of planning and instability of government policies and programs in the agricultural sector, especially in agricultural and natural land management and tenure. This driver, together with severe climate changes such as drought and floods, have significantly increased the risk of agricultural activity (Azadi et al., 2018) and have also accelerated land fragmentation. Accordingly, we have classified the main drivers of agricultural land fragmentation into four main factors, including economic, social, political, and environmental factors.

Currently, the government has pursued two main groups of policies against changes in agricultural land use and fragmentation: a) promoting land consolidation and conservation through policies such as tax exemptions, technical and financial support for land leveling and grading, and creating irrigation systems, and b) adopting punitive policies, such as depriving small and fragmented farms of technical and financial support and avoiding giving ownership to fragmented lands. Despite such preventive policies, why is the ALF problem still existing and the agricultural lands still being fragmented? This is the major question that this study aims to explore using the GT methodology.

2. Materials and methods

This study uses the normal and strategic form of games. A strategic game has at least three components: a set of players, an action set of each players, and the players' preferences or ordering of the action profiles from the best to the worst. To construct the strategic form of the game model according to the ALF situation in Iran, these three main component sets are as follows:

a) *Set of players:* two main groups of stakeholders were set as two main players, player L (farmer or agricultural landowner) and player G (government). Therefore, the players set is [G, L].
b) *Action set of players:* the common policies or actions of government are punishing land use change and fragmentation or encouraging land consolidation. Therefore, the action set of player G is [P (Punish) and E (Encourage)], in which under action P, the government will penalize landowners if they fragment their land, and under action E, the government will encourage the landowners if they do not fragment their land. The action set of player L is [F (Fragment) and D (Don't-Fragment)], in which the farmer (landowner) has two actions including fragmenting or not fragmenting the land.
c) *Preferences of the players:* the preferences of each player depend on his or her payoffs under each strategic position (action profile) of the game. This game has four main positions (FP, FE, DP, and DE). Considering these positions, the payoff of each player is according to Fig. 2. Payoffs are ordinal or cardinal (continuous) measures or values which indicate profit, quantity, utility, or only the simple rank of players' outcomes. The payoff of each player from each situation of the ALF game in cardinal (the amount of benefit earned by players) and ordinal (the rank or the preference of players in each situation) shapes are presented in Figs. 2 and 3. The order of preferences per each player are as follows:

Players		G	
	Actions	P	E
L	F	u_L (F , P) u_G (F , P)	u_L (F , E) u_G (F , E)
	D	u_L (D , P) u_G (D , P)	u_L (D , E) u_G (D , E)

Fig. 2. The payoff matrix of the ALF game in strategic form.

Players		G	
	Actions	P	E
L	F	0 , 1	1 , 0
	D	2 , 3	3 , 2

Fig. 3. The players' payoff of the ALF game based on ordinal preferences (when PV and EV are sufficiently large compared to VF and VN).

The government prefers non-fragmented lands to fragmented ones. Since Iranian farmers are more likely to react to punitive policies than encouragement, and given that encouraging is costly, the government prefers DP to DE. However, and if necessary, the government is ready to encourage farmers to avoid fragmenting their lands. If the farmers fragment their lands, the government prefers to impose a penalty. According to these assumptions, the order of preferences for the government (utility of government: u_G) for each situation of the ALF game will be as follows:

$$u_G\,(D,\,P) > u_G\,(D,\,E) > u_G\,(F,\,P) > u_G\,(F,\,E).$$

From the farmers' side, due to the socio-economic benefits of the land ownership in the rural areas (FAO, 2002, 2016; Palmer et al., 2009), farmers prefer not to fragment their lands. In the case of Iran, the size of the land has a significant impact on the socio-economic status of farmers, hence, their preferences is not to fragment their land. However, if they do, they prefer that the government does not penalize them. Of course, in practice, farmers' preferences are more complicated. Their preferences are tied to many variables, however, their most preferred options are: i) the expected value of non-fragmented land (VN) which can be assumed to be equal to its present production value or expected revenue over the production life, ii) the expected value of fragmented land (VF) which can be assumed to be equal to its current value, iii) the punishment value of land fragmentation (PV) which is equal to the value of penalty, and vi) the encouragement value of non-fragmentation (EV) which is equal to the value of technical and financial support of government from farmers who have not fragment their lands (due to preventing land fragmentation or performing land consolidation). Accordingly, the order of the farmer's preferences (utility of landowner: u_L) for each situation of the ALF game will be as follows:

$$u_L\,(D,\,E) > u_L\,(D,\,P) > u_L\,(F,\,E) > u_L\,(F,\,P).$$

Fig. 3 represents the order preferences of players in the ALF game based on the ordinal preferences. However, as mentioned above, the preferences of the farmers are affected by several variables including VN, VF, PV, and EV. Therefore, by considering these variables, the estimated cardinal payoffs of each player will change as shown in Fig. 4.

Players		G	
	Actions	P	E
L	F	VF-PV PV	VF 0
	D	VN VN	VN+EV VN-EV

Fig. 4. The players' payoff of the ALF game based on cardinal preferences.

According to Fig. 4, for example, the estimated payoff of player L from action profile (F, P) depends on the value that he/she will gain from a piece of fragmented land (VF) minus the punishment value (PV) that should be paid to the government for the fragmented land. In the same way, the estimated payoff of player G for action profile (F, P) is equal to the value that G will gain from punishment (PV), etc. Here, we can consider a wheat farmer who has a farm with an area of five hectares as an example. The average yield of wheat in Iran is around 5 tons/ha and the net income from wheat cultivation per hectare is 50 million Rials (50 MR / ha). We assume that the farmer needs to sell one hectare of his farm. The average price of each hectare of irrigated land in Iran is about 500 MRs. If we assume that the government's financial support value is 10 MRs per hectare, the VF, VN, PV, and EV values will be as follows:

a) VF = 500 :average price of each hectare of irrigated land in Iran,
b) VN ≈ 471 : present value (P-value) of the cash/income flow of one hectare of the wheat farm (c = 50 MR / ha) with 30-year product life (t = 30 Years) and 10 % interest rate (r = 0.1) that is calculated as $P - \text{value} = c[(1 - (1+r)^n)/r] = 50\ (1\text{-}(1.1^{30})/0.1) = 471.3)$,
c) PV = 90 (it is equal to the cost to be paid by the government for importing five tons of wheat with an average world price per ton of 200 $, 1$ = 90,000 Rials), and
d) EV = 10*5 = 50 (i.e. 10 is assumed to be the government's financial support value per hectare and 5 is the average size of farm ownership in Iran).

The payoff values of this game for each situation are shown in Fig. 5.

3. Results and discussion

As defined earlier, a Nash equilibrium (NE) is a list of action profiles (strategies) which has the property that no player can change his strategy and get a better payoff in a unilateral way. As shown in Fig. 3, the ALF game has only one NE. It means that under ordinal preferences, the best actions of the farmer and government are D and P, respectively. Therefore, the action profile (D, P) is the best response and SD strategy with considering the whole system without considering the interests of each individual player within the system. The DP strategy is always primarily better than any other strategy for any other player's action profile as well. If this position is the only Nash equilibrium of this game, and if this is the strictly dominant strategy of the ALF game as well, the question is why agricultural lands are still under more fragmentation. There are many studies that confirm ALF as a common phenomenon in developing countries (Van Hung et al., 2007) such as Iran (Abdollahzadeh et al., 2012), Ethiopia (Paul and wa Gĩthĩnji, 2018), Sri Lanka (Wickramaarachchi and Weerahewa, 2016), China (Nguyen et al., 1996), India (Manjunatha et al., 2013), Tanzania (Kadigi et al., 2017), and Romania (Vijulie et al., 2012). In the case of Iran, according to the databases of the Statistical Center of Iran, from 1989 to 2015, the average land area of each farming household decreased by about 1.2 ha (from 6.1 ha to 4.9 ha). The response to this question based on GT is because the players of this game do not act by considering the whole system payoffs, but they act by considering the best individual response of themselves. In addition, the estimated players' payoffs of the ALF game depend on some other variables including VF, VN, PV, and EV values. Moreover, the lack of farmers' knowledge about the long-term impacts of their decisions and the value of ecosystem services value of their lands is another driver that should be considered. For example, in Rwanda, lack of knowledge among people led to problems in the land management process (Ericsson and Lindberg, 2018), or in Chile, a serious lack of knowledge about the relationship between land-use change and biodiversity and ecosystem services was reported as the main problem in the field of land-use planning (Rodríguez-Echeverry et al., 2018). It seems that because of a desire for more benefits and lack of knowledge about the value of ecosystem services, humans changed many natural ecosystems into cropland and buildings (Balvanera et al., 2006; Chen et al., 2014; Costanza et al., 1997; McIntyre and Lavorel, 2007) or fragmented the croplands. In addition, it is clear that the ALF game has a non-collaborative structure in which players cannot form the constructions necessary to encourage collaboration, or they are not encouraged to do so. In this regard, the agents can also resort to certain situations in a collaborative game to enable collaboration and optimum results for everyone (Faliszewski et al., 2016). Non-cooperative games are a group of models in which the choice of players is based on their interest and does not refer to the overall results of the game (Turocy and von Stengel, 2001), in other word, players should choose a strategy that only optimizes their payoff, not the whole system payoffs. The other key feature of the non-cooperative games is the absence of an external authority to enforce rules.

This key feature is also true in Iran's agricultural land management. There are many studies that confirm the desire of farmers toward ALF in developing countries (Manjunatha et al., 2013; Nguyen et al., 1996; Paul and wa Gĩthĩnji, 2018; Van Hung et al., 2007; Wickramaarachchi and Weerahewa, 2016) like Iran (Abdollahzadeh et al., 2012). In China, at the end of June 2016, out of the total 1.3 billion contracted lands, 460 million were agricultural contracted lands which means that land fragmentation exists (Xie and Lu, 2017). Wickramaarachchi and Weerahewa (2016) indicated that ALF is the main challenge of agricultural development in Sri Lanka that has adversely affected the land productivity. Van Hung et al. (2007) believed that land fragmentation is common in Vietnam, especially in the North. They had concluded that small-sized farms are likely to be more fragmented.

According to the definition of Pareto optimality, all action profiles of the ALF game (FP, FE, DP, and DE) in Fig. 3 are Pareto solutions since there is no alternative situation that would make one player's payoff better off without making other player's payoff worse off. According to Pareto optimality, anyone would prefer a situation that is cheaper, more efficient, or more reliable as the one that comparatively improves one's condition. What does this mean in an ALF game? The main important lesson is that the current policies and programs in this area are strictly ineffective. In such a way, there is no incentive for any changes in the current strategy. The continuous trend of ALF in many countries including Iran is a powerful sign of this claim (Niroula and Thapa,

Players		G	
	Actions	P	E
L	F	**410** (500 - 90) / **90**	**500** / **0**
	D	**471** / **471**	**521** (471 + 50) / **421** (471 - 50)

Fig. 5. An example of the players' payoff of the ALF game

Fig. 5. An example of the players' payoff of the ALF game.

Players		G	
	Actions	P	E
L	F	VF* / 0*	VF* / 0*
	D	VF* / VF*	VF* / VF*

Fig. 6. The payoffs and the Nash equilibrium of the ALF players when VF = VN, and PV and EV are equal to zero.

Players		G	
	Actions	P	E
L	F	VF-PV, PV*	VF, 0
	D	VF*, VF*	VF + EV*, VF-EV

Fig. 7. The payoffs and the Nash equilibrium of the ALF players when VF = VN, and PV and EV are higher than zero.

Players		G	
	Actions	P	E
L	F	VF, 0*	VF, 0*
	D	VN*, VN*	VN*, VN*

Fig. 8. The payoffs and the Nash equilibrium of the ALF players when VF < VN, and PV = EV = 0.

Players		G	
	Actions	P	E
L	F	VF-PV, PV*	VF, 0
	D	VN*, VN*	VN+EV*, VN-EV

Fig. 9. The payoffs and the Nash equilibrium of the ALF players when VF < VN, and PV and EV > 0.

Players		G	
	Actions	P	E
L	F	VF*, 0*	VF*, 0*
	D	VN, VN*	VN, VN*

Fig. 10. The payoffs and the Nash equilibrium of the ALF players when VF > VN, and PV = EV = 0.

2005).

Nevertheless, as mentioned above, farmers usually make their decisions and act by considering many variables. Therefore, to provide a better understanding about the issue of land fragmentation, it is assumed that the most important variables are VN, VF, PV, and EV. As a result, the value that a farmer gains from a fragmented land (VF) and its agricultural product value (VN), except the cost of inputs and selling price of the product, is related to the land quality (including both land

Players		G	
	Actions	P	E
L	F	VF-PV, PV*	VF, 0
	D	VN*, VN*	VN+EV*, VN-EV

Fig. 11. The payoffs and the Nash equilibrium of the ALF players when VF > VN, and PV and EV are higher than (VF-VN).

productivity and land position). Depending on the value of these two variables, the following three main modes may occur:

a) VF = VN
b) VF < VN
c) VF > VN

Now, under these three conditions and with considering that PV and EV amounts are zero or higher than zero, the payoffs of any players in the ALF game will be as shown in Figs. 6–11.

Based on Fig. 4, if the government wants to prevent land fragmentation under punishment and encouragement policies, it is respectively necessary to have VN>(VF–PV) and (VN + EV)>VF. It means PV and EV should be greater than VF-VN. Therefore, when VF = VN, if PV and EV are equal to zero the payoffs and the Nash equilibrium of the ALF players will be as Fig. 6, in which all strategies are Nash equilibrium and there is no POE situation. This means that there will be no definite and optimal situation for ALF game.

However, when VF = VN but PV and EV are higher than zero, the game will have one Nash equilibrium (DP) (see Fig. 7). According to this scenario, DP and DE definitely are POE, and FE definitely is not POE. Moreover, action D for player L is strictly dominant. Therefore, when VF = VN, government not only should not adopt a passive policy (PV = EV = 0) but also it should consider both penalty and encouragement.

For the second condition (when VF < VN), if PV and EV are equal to zero the payoffs and the Nash equilibrium of the ALF players will be as Fig. 8, in which DP and DE strategies are Nash equilibria and action D for player L is strictly dominant. DP and DE are two POEs of the game. Here, under any policy of government (player G) the best response of farmers (player L) will be to not fragment their lands. Therefore, the government does not require PV and EV to keep the opponent (farmer) in play D, because he or she has no incentive for ALF, and the government should help maintain the existing conditions (VF < VN).

However, although under the second condition government does not need to impose penalty or encouragement to prevent ALF but whenever it considers an amount more than zero for PV and EV the payoffs of players and Nash equilibria of the ALF game will be as in Fig. 9. Under this new situation, the game has only one Nash equilibrium (DP), action D is strictly dominant for player L, and DP and DE are POEs of the game. Therefore, in this case player L has no incentive to choose action profiles FP and FE.

Based on the third condition (when VF > VN), if government does not impose penalty or encouragement (PV = EV = 0), the ALF game will have two Nash equilibriums (FP and FE) and the action F will be strictly dominant for farmers (Fig. 10). It means, if government wants to prevent ALF, not only it should not be passive, but also it should adopt a pro-active policy including both penalty and encouragement. All action profiles of this game are POEs. It means there is no incentive for each player to change his/her current strategy.

In this regard, under the third condition, to prevent ALF, the penalty amount imposed by the government requires to be more than the

Players		G	
	Actions	P	E
L	F	210 , 90*	300 , 0
	D	471* , 471*	521* , 421

Fig. 12. The payoffs and the Nash equilibrium of wheat farm example when VF (=300)<VN(=471).

difference between VF and VN or PV>(VF-VN). In a same way, under encouragement policy, to prevent ALF, it is required to (VN + EV)>VF or EV>(VF-VN). It is because, only under this condition, VN would be more than (VF-PV); and (VN + EV) would be more than VF (or the best response of player L would be D). As a result, when VF > VN, the PV or EV amount that is imposed by the government requires to be more than the difference between VF and VN (EV and PV>(VF-VN)). Based on Fig. 11, only under this scenario (EV and PV>(VF-VN)), the Nash equilibrium of the game will be DP, and D is the strictly dominant action for farmers. In other words, the best response of the farmer will be D.

The Pareto solutions of this condition are DP and DE. It means that only the farmers who have done ALF previously have the incentive to change their actions. In other words, under this condition, there is no incentive for ALF.

Given the above results and explanations, we can return to the example of wheat cultivation lands. In Fig. 5, under the current condition (when VF (=500) > VN (=471)), the best response of the farmer to action E (the encouragement policy) of the government is D. It is because the amounts of PV and EV (90 and 50) are more than VF-VN (500−471 = 29). In a same condition, if PV and EV are less than 29, the best response of the farmer was F. However, if VF = VN = 500 and PV and EV are more than zero, the best response of the farmer will be D (preventing ALF) and action D is strictly dominant for him/her. Within the current situation (VF = VN = 500), if PV and EV are equal to zero. Player L will have not any strictly dominant action. Therefore, to avoid ALF, government requires considering both penalty and encouragement. It indicates that by raising the benefits of agricultural activity, the incentive for ALF will decrease. Kalantari and Abdollahzadeh (2008) and Abdollahzadeh et al. (2012) indicated that along with raising production cost and production yield, ALF probability will increase, and Niroula and Thapa (2005) in a study in south Asia indicated that agricultural land quality affects ALF because of its direct impact on land productivity and crop production.

Now suppose a new condition for the wheat model based on which the VF value is equal to 300 instead of 500. The players' payoffs will change as shown in Fig. 12. Under the primary condition (VF = 500), the best response of player L to action E of player G is F, but under the new condition, the best response of L to both P and E actions of G is D. It means action D is strictly dominant for player G.

Therefore, the decision making of farmers to adopt F or D actions is depended on the value of the components that affect his/her payoff (VF, VN, PV, and EV), and their ratio. Consequently, if the government seeks to prevent ALF, it should adopt true policies to influence the amounts of PV, EV, VF and VN or their ratio to encourage or enforce farmers to choose action D instead of F. In this regard, the government needs to increase landholders' expected incomes from farm or to choose policies that decrease the price of agricultural lands (in fact, this can help to decrease the expected value of land fragmentation and to reduce the incentive for the farmer to earn more money from fragmented lands). There is some literature that indicates the impacts of production cost, production yield, land quality, etc. on ALF (Abdollahzadeh et al., 2012; Alemu et al., 2017; Kalantari and Abdollahzadeh, 2008; Niroula and Thapa, 2005) in different countries including Iran.

Fig. 13 indicates the changes in PV and EV under different values of VF and VN (VF-VN). As the difference between VF and VN increases (the ratio of VF / VN), if government wants to encourage farmers to prevent ALF, the amount of PV and EV should also increase. Therefore, the government needs to apply different ALF policies for different conditions. The VF and VN are functions of various variables such as agricultural products costs (Pc), agricultural products price (Pp), amount of agricultural products (Q), and agricultural lands price (Lp). Consequently, the government needs to manage these variables to change the VF/VN ratio.

In the case of Iran, during 2008–2019, Pp of wheat increased by 655 % (from 2250 to 17,000 Rials) and its Pc (because of inflation) increased about 530 %. In other words, the mean annual growth of Pp and Pc have been 20.9 % and 19.2 %, respectively. It means that the earnings of farmers from wheat cultivation have increased over 2008–2019.

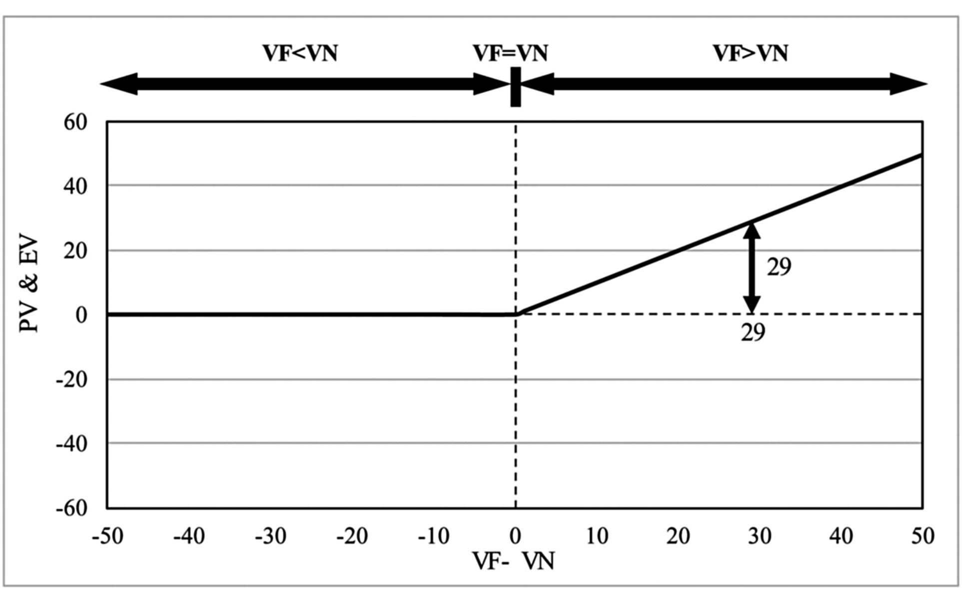

Fig. 13. The changes in PE and EV under different values of VF and VN (three conditions: VF < VN, VF = VN, and VF > VN). 29 is the minimum amount of PV and EV for wheat example when VF is 500 and VN is 471.

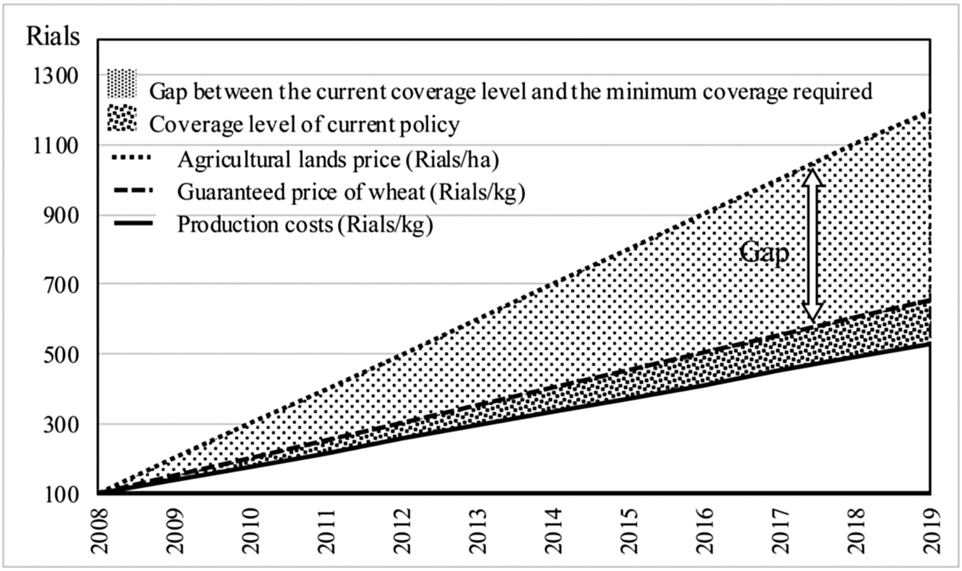

Fig. 14. The trends of wheat Pp, Pc, Lp, and its impacts on PV and EV over 2008-2019. Gap between optimum and current amount of PV and EV has increased over the time. Therefore, the farmers' tendency to ALF has increased (the base value assumed as 100).

Accordingly, why has the farmers' tendency to ALF increased? The answer to this question will be easier once the trend of change in Lp is investigated simultaneously. Based on Fig. 14, Lp has increased two times more than Pp over 2008–2019 (about 1200 %). It leads to raise the distance between VF and VN over time (Fig. 14). As a result, there is a gap between VN and VF and this gap has increased every year. It is because the rate of increase in Lp has been more than raising in the agricultural product value. It seems to prevent ALF government has no choice except to manage and reduce this gap. Obviously, to manage this gap, the government should a) control the raising of Lp (reduce VF), b) increase the profitability of the agricultural sector by reducing production costs and increasing productivity and efficiency in the agriculture sector (increase VN), and c) adopt a true encouragement and penalty policy. If the government of Iran likes to manage ALF using PV and EV policies, when VF > VN it is necessary to increase PV and EV more than the difference between VF and VN. Under this condition, the best response of farmers to each play of government will be D, because there is no incentive for him/her to play D action instead of F.

Table 1
The study's answers and practical implications in brief.

No	Research questions	Study's answers and practical implications
1	Is game theory useful for the analysis of land issues such as ALF?	The main findings showed that game theory can help to better understand the ALF problem through improving our understanding about the structure of the ALF problem, its players, and their decision-making, actions and the payoffs of each action.
2	What is the structure of ALF as a strategic game (players, players' actions, and players' payoffs)?	The results indicated that the ALF as a game has at least two main players include farmers (L) and government (G). Each player has at least two actions, and each action have specific payoff with regard to some variables include VN, VF, PV and EV that is related to the land quality.
3	What are the different strategic situations of ALF as a strategic game?	According to the main findings, the ALF as a strategic game has four different strategic situations include FP, FE, DE and DE. Although the action profile DP (in which the farmers do not fragment their land, and the government will penalize the farmers if they fragment their land) is a strictly dominant strategy, but the farmers tend to FP strategy. It is because the farmers only consider their best individual response and ignore the whole system payoffs.
4	What is the best action of each player (government or farmer) against the other player's actions?	This study showed that the best action of each players in the ALF game is different based on the value that a farmer gains from a fragmented land (VF) and its agricultural product value (VN) that they are related to the land quality. For example, when VF > VN, the best response of farmers to each play of government will be D (Don't-Fragment), instead of F (Fragment).

4. Conclusion

This study has presented and constructed the ALF strategic game model to analyze and describe the space of farmer and government decision-making as the main players of the ALF game, based on the case of Iran. Toward this end, at first, this study constructed two types of games with regard to ordinal and cardinal preferences of players. Then, the order of preference (utility) of each player under both games is identified. After that, the Nash equilibrium and the Pareto solutions of the games were described. The results of this study showed that although the action profile DP (in which the farmers do not fragment their land, and the government will penalize the farmers if they fragment their land) is a strictly dominant strategy, the farmers tend to fragment their agricultural lands (Abdollahzadeh et al., 2012; Barati et al., 2015). For instance, the Statistical Center of Iran has reported that the average land area of each farmer household decreased by about 1.2 ha (from 1989 to 2015). It also has claimed that this trend of ALF in many countries including Iran will continue in future (Niroula and Thapa, 2005). What is the main root of the conflict derived from ALF? In other words, despite these negative impacts, why do farmers tend to fragment their lands? Based on GT, the core of this conflict is the fact that the players (farmers) only consider their best individual response and ignore the whole system payoffs. Moreover, they do not have any alternative actions to perform in a specific situation (e.g., in Iran, farmers have no alternative actions against the inheritance law). In addition, the ALF game seems to be played in a non-collaborative situation in which players cannot form the structures required for collaboration. On the other hand, the agents can employ certain situations in a collaborative game to achieve optimum results for everyone. The other key component of non-collaborative games is the lack of an external authority to enforce rules that are also applied to the management of land in Iran. The lack of true rules and an external authority to control the space of the game in which farmers and government make decisions about lands use are the other challenges of ALF, as well as further aspects of land management such as land use change in Iran and many other developing countries. Although non-collaborative games anticipate the actions of people in a game by finding the Nash equilibrium, the result of real word problems, such as the ALF game, is often different from what the theory predicts.

This study also analyzes the ALF game under cardinal preferences that are closer to the real world of ALF. With regard to cardinal preferences, based on the value of land and the value of its products, at least three main modes or states may occur: a) VF = VN, b) VF < VN, and c) VF > VN. In other words, the actions of farmer and government in this mode are diverse and related to the state of the game. This study indicates that the most complicated state of the ALF game, in cardinal preferences form, will be the third one in which the PV and EV have more important roles in managing ALF. In this state, if player G wants to enforce player L to choose action D, it should identify PV and EV > (VF-VN) and vice versa. It means that if the government aims to apply any incentive or punitive policies to manage ALF, the value of these policies (the amount of penalty or encouragement) should be at least more than the difference between the value of the fragmented land and the production value of the same land. Another policy implication is to increase the value of the agricultural production (by reducing production costs or raising the price of products) or reduce the value of each unit of agricultural land area (changing the right side of the function). Studies have shown that ALF incentives for decrease when the value of the agricultural production increases. For example, according to Kalantari and Abdollahzadeh (2008) and Abdollahzadeh et al. (2012), along with reducing the agricultural production cost, the ALF probability decreased in Iran. Also, according to Niroula and Thapa (2005) study, the agricultural land quality affects ALF given its direct impacts on land productivity and crop production. It should also be considered that these policies are based on the current structure of this game, but there are also many other alternatives for the current structure of this game, such as changing the elements of the game (especially actions) or the game structure. For example, the government can suggest some alternative actions for farmers such as renting their lands to state and cultivating them in a cooperative manner. In addition, the government can apply some different strategies or actions including punishment, subsidies or financial support for the farmers or landowners to keep their farms over time.

Therefore, this study constructed the strategic structure of farmer and government decision-making about ALF in different strategic situations in the ALF strategic game. It seems that the GT is a useful tool to analyze land issues such as ALF. ALF is a strategic situation in which the outcomes for farmers or the government depend not only on what one of them does but also upon what others do. Therefore, the ALF management situation depends on what others do no matter how good or how smart the government or farmers are. When the main actions of the farmer (F and D) and government (P and E) in ALF were defined, this study indicated the payoffs of a farmer and government in different strategic situations. It also described the way that a farmer or government used to act against each other. For future study, it will be useful to develop and improve the ALF game under more complicated situations such as mixed, imperfect information and Bayesian form of the games or the extensive form of the ALF game. Table 1 summarizes the answers of this study to each of the main research questions.

CRediT authorship contribution statement

Ali Akbar Barati: Conceptualization, Data curation, Formal analysis, Methodology, Writing - original draft. **Hossein Azadi:** Supervision, Validation, Writing - review & editing. **Jürgen Scheffran:** Supervision, Validation, Writing - review & editing.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:10.1016/j.landusepol.2020.105049.

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