

Article

Advancing Fair Division in Overseas Farmland Investment via Shapley Value

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Abstract: Currently, a global hunger and malnutrition crisis is spreading throughout various regions worldwide. Overseas farmland investment endeavors to enhance regional food production through international cooperation but faces the challenge of ensuring a fair division. Our study develops a more equitable method: we have modeled overseas farmland investment as a cooperative game, reallocating benefits among host countries and investing countries. The application of our results to real data indicates that there is not only significant scope for improvement for host countries and overseas investors—which gain added benefits—but also a remarkable contribution made to rural development in terms of increased productivity. The cooperation to increase farmland yield through technology and capital transfer can be achieved in practice. In this context, transnational cooperations can provide additional benefits to participants, which can offer an important motivation for collaborators.

Keywords: overseas farmland investment; food security; fair division; cooperative game; Shapley value



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1. Introduction

The capacity of agriculture to feed expanding global populations has been a focus for generations, and it continues to be a significant issue within international policy as well as scientific research. The issue of global food security is anticipated to represent one of the most pressing challenges in the forthcoming decades and beyond [1,2]. Currently, a global hunger and malnutrition crisis is spreading throughout various regions worldwide, with 343 million people expected to be afflicted by food shortage [3]. By 2050, global agricultural production will need to feed nine billion people, and the majority of population growth is expected to occur in developing and impoverished countries [4]. This will place more responsibilities on local governments and international organizations, as economically disadvantaged countries with inadequate public resources require international financial aid to improve the provision of public services that will jointly support the agrifood system [5]. It is projected that an annual investment of no less than USD 83 billion is necessary to guarantee food security [6]. The present recessionary context, however, makes it challenging for numerous developing countries to augment their budgetary allocation toward the advancement and transformation of agrifood systems, a crucial component in the achievement of Zero Hunger, Sustainable Development Goal 2 [5].

In this context, overseas farmland investment (referred to herein as OFI) can serve as an effective way to increase farmland production and address the global food crisis. OFI is characterized by the transfer of farmland property rights from host countries to overseas

countries, resulting in the conversion of farmland from small-scale production to transnational investment targets for agricultural purposes. Overseas investment in the agricultural sector is regarded as an urgent factor in the otherwise neglected transformation of agrifood systems [4,6]. In practice, a significant proportion of transnational investors have sought to build agricultural and biofuel crop plantations on the cheap and fertile farmlands of Africa and Southeastern Asia during and after the global economic crisis [7–10]. The heightened anticipation of possible financial gains derived from the agricultural sector has made OFI a progressively appealing choice for overseas investors [7]. To date, overseas investors have acquired more than 90 million hectares of arable land globally [11]. Consequently, foreign investors possess roughly 6% of the total arable land worldwide. OFI has been profoundly reshaping global agrifood systems, as well as the livelihoods and social trajectories of individuals and communities [8,11]. Conversely, the terminology “land grab” or “land rush” is frequently employed to characterize the occurrence of OFI, while a group of scholars emphasize the detrimental impacts of OFI on aspects such as food security, the ecosystem, and the well-being of indigenous people in host countries [12–15]. Investors from affluent developed countries are often portrayed as predatory entities, as they ensure their own food security by plundering resources at the expense of vulnerable populations in underdeveloped nations [16,17].

However, despite recent headlines about “land grab”, this issue is subject to discussion, because this debate is often dominated by preconceived notions [18]. To promote productivity and mitigate food shortages, foreign investors incorporate technology transfer to the host countries through OFI [11,13]. In the millennium development project, overcoming hunger not only relies on increasing soil fertility but also on methods such as technology transfer and cooperation between national and non-government departments [19]. A stream of evidence suggests that OFI has significantly contributed to boosting food security and promoting economic development, along with other social advantages, especially in countries with lower and middle incomes [20–24]. However, developing countries generally lack economic security systems, and the industrial policies proposed by host governments may also lean toward investors, thus presenting a potential risk to the welfare of local inhabitants [25]. Notably, developed countries, based on their own needs, invest in their products globally [26]. In this respect, overseas investment is typically seen as economic colonization. The negative impacts of OFI on local populations have received considerable attention in existing studies. A variety of studies have consistently demonstrated a correlation between OFI and the occurrences of social unrest, instability, land conflicts, and resource dispossession [25,27]. This is more noticeable when the expropriated target land has already been occupied and cultivated by local residents [27–30]. Hence, the fundamental concern revolves around the design of compensating mechanisms.

The question then becomes the following: How do we realize fair division in transnational farmland-based investment? The issue of fair division has emerged as a serious barrier to OFI producing global food security in a cooperative context. The concept of fair division pertains to the mathematical analysis of distributing a collection of divisible objects or limited resources among several individuals, with the objective of determining an equitable distribution that benefits all parties concerned. Initiated by Steinhaus [31], the research on fair division has attracted substantial interest from various academic disciplines, such as mathematics, economics, and computer science. Allocation problems emerge when participants have divergent preferences regarding the allocation options for a shared entity. Game theory is extensively employed in the subject of political science, particularly in the traditional literature of division problems, providing a range of methodologies to address the problem [30]. Although game theory has found applications in various fields, to the best of the authors’ knowledge, its applications to OFI have been very limited. A recent

study demonstrated an emphasis within the research community on economic analysis of fair compensation within the context of non-cooperative games [30]. However, the cooperative game is more conducive to the analysis of fair division in transnational agricultural investment. In the context of a non-cooperative game, it is notable that the interdependence among players and the potential for the formation of multiple small alliances were not factored into the game analysis. In investment negotiations among several states, they may cooperate to reach a mutually beneficial agreement on the matter of sharing profits in a way that benefits all participants. As the concept of fair division in a cooperative game promotes cooperation among players, it provides a useful tool for investigating fair division within a cooperation framework.

Fair division is regarded as the process of allocating a set of divisible products among recipients. One of the prevalent fair division problems is profit allocation. In this study, we seek to contribute to the literature by using the Shapley value, a cooperative game method developed by Shapley [32], to propose a fairer way of sharing the total benefits of OFI between host countries and overseas investors. By calculating the Shapley value corresponding to each player, the marginal contribution of each player to the overall outcome can be determined. The result shows that the Shapley value can be used to achieve a fair division of surplus profit among host farmland owners cooperating with overseas investors, resulting in higher productivity and profit. Although our method is fairly standard when compared to those in recent studies, it is a novel solution to a problem that is deeply rooted in OFI.

2. Literature Review

2.1. OFI May Be a Win–Win Solution

From the mid-2000s, the relatively high and volatile prices of agricultural products triggered an unprecedented wave of OFI in developing countries, largely due to the shortage of natural resources and the increasing demand for food and biofuel [20,33]. Before that, in the 1960s, Japan demonstrated a strong interest in OFI, driven by guaranteeing agricultural demands for domestic residents [34]. Overseas investors have strong incentives in the form of the significant profits that may be achieved through improving the productivity of land already cultivated by local residents [7,13]. In other words, countries with low productivity, abundant unused arable land, and huge agricultural potential are attractive to international investors. Recently, Southeast Asia and Sub-Saharan Africa have been the primary regions focused on due to their large availability of affordable land, low labor expenses, and excellent farming climate [18,35].

What also remains crucial in the case outlined in the preceding section, besides obtaining cheaper food from farmland, is the overseas investment and development opportunity for host authorities [10,20]. For the most part, governments in host countries generally encourage overseas investments, as the possible benefits are enticing. OFI can foster land productivity and food security via technology transfer in host countries [36]. In addition, OFI is often viewed as a mechanism for job creation and the construction of collective institutions [15,37]. Host governments have endeavored to create a conducive atmosphere for external investment to address the lack of development aid and persistent underinvestment in the agricultural sector. Given the limited availability of capacity financing in the agricultural sector, leasing abandoned farmlands has been considered an efficient way to tackle the persistent lack of critical investment [38]. That is why OFI can serve as a way to promote rural development and enhance the country's trade exchanges. On balance, OFI has the capacity to provide a unique and unparalleled opportunity for host countries.

It is worth mentioning that OFI contributes to pushing the agrarian system from small-scale farming to commercial agriculture, especially driven by the “internationalization” and

“financialization” of agricultural production factors [38]. Unfortunately, another concern is that most of the host countries have characteristics such as incomplete land tenure systems, a lack of credible inclusive institutions, and a weak business climate in terms of disclosure and openness [39]. Although the strategic importance of OFI has been recognized and large-scale land acquisitions are also growing fast, most land transactions are marked by an absence of supervision and transparency [8]. The presence of a deficient institutional framework has the potential to undermine favorable outcomes and pose risks to both food security and human rights. OFI could be a win–win solution if the risks are mitigated effectively.

2.2. Fair Division in the OFI

Research on land values has garnered significant attention in the field of economics. It has been conventionally considered that land is a fixed input in production, both in terms of its quantity and mobility. Nevertheless, the surge in transnational land acquisitions demonstrates the growing mobility of land ownership, allowing overseas countries to expand their land resources across national boundaries [40]. Over the past few decades, overseas investors have surprisingly shown a strong interest in farmland, with its demand swiftly rising at an unprecedented rate [41,42]. Land has played a prominent role in economic history. Given the significant role that agricultural activities play in human society, farmland can be seen as the focal point of value theory, as it serves as the primary source of all products. Agricultural activities mostly rely on farmland and other natural resources. Land appreciation is essentially expressed as the increase in the productivity of land, which manifests itself as an increase in land rents. Essentially, OFI stands for the transfer of land use rights on global markets. In a transaction, the price of farmland refers to the future ground rent that is paid by foreign investors to the grantor. The profits received by the host countries can be understood as the purchase rent derived from the land lease agreement. The productivity of land, determined by its fertility, is the primary factor influencing farmland rent.

Fair division is the act of distributing resources among multiple participants in an equitable manner, which in this study refers to the allocation of agricultural profits produced by investment sites. From a global point of view, OFI can be viewed as a manifestation of the growing disparity between the worldwide supply and demand for land [40]. The impending scarcity of food in the next few years presents a disproportionate threat to the impoverished and vulnerable segments of the global population [3,5]. The pivotal role of OFI becomes evident, along with the need to provide financial resources to the agricultural sector. We recognize the crucial contribution that other fields of study play in comprehending the complex and diverse aspects of OFI. In this context, the tremendous media and policy attention on OFI has contributed to an extensive debate on whether OFI will effectively address global food insecurity or merely perpetuate contemporary colonialism [42]. Currently, the debates are shifting from simplistic value judgments to a more thorough and intricate examination of this issue [33]. While overseas investors contribute to closing the production gap by replacing traditional farming with intensified agriculture [24,36], such foreign investments may increase agricultural productivity and threaten local food security by redirecting key crop production toward rich countries and outside markets simultaneously [11]. The current wave of global land rush is unprecedented, notwithstanding the historical and existing extractive linkages between the ‘Global North’ and the ‘Global South’ since colonialism and capitalism [15].

The current transnational investments play a growing role in the interaction between the ‘Global North’ and the ‘Global South’, connecting the expanding demands for agricultural products with farmland in developing countries. The execution of such investments

frequently aims to generate agricultural commodity backflows to overseas investors, developed foreign governments, and global markets. Cooperation among overseas investors and host landowners can enhance productivity by sharing technology, which leads to increased income and ensures food security [19,24]. The extant research on OFI has focused exclusively on the farmland rent component. Studies that investigate the problem of fair compensation for local inhabitants and indigenous populations impacted by OFI have shown a greater systematic interest on the topic of land value [30,40]. From our point of view, despite the land value being extensively discussed, the question of fair division in OFI has been largely ignored in the existing literature.

This study attempts to design a fair distribution scheme for OFI via the cooperative game approach. OFI incentivizes cooperative behavior among host landowners and overseas investors by establishing a framework where the profits of agricultural products are clearly defined and shared. The cooperative game framework can be applied to the pooling and redistribution of land property, which entails the facilitation of collective agreements among host landowners and overseas investors. It aligns each player's outcome with their contribution to the team effort, which ensures that all participants are aware of the advantage of forming an alliance, thus fostering a stable coalition that can effectively respond to the transformation of agrifood systems. This collaborative approach not only maximizes individual and collective profits but also encourages sustainable practices that can benefit the global food market.

3. Methodology

Cooperative game situations in which players are partially cooperative and partially conflicting are, therefore, distinct from non-cooperative game models in which players act independently of the action of the other players [43,44]. Two distinct methodologies enhance our comprehension of strategic reasoning and reflect different types of strategic considerations. The non-cooperative game, including the best-known example of the prisoners' dilemma, focuses on what individual players can achieve under the non-cooperative condition. On the other hand, for cooperative games, it is assumed that each group of players can form a coalition that results in a specific amount of profit for them [43]. The objective of the cooperative game is to examine which coalition is necessary to form and how to divide its worth to members within a coalition. In this regard, the cooperative game has received much attention because it provides an efficient and unique solution for the allocation problem in the game theory framework.

3.1. Cooperative Game

A cooperative game with transferable utility can be represented by a pair $(N; \nu)$, such that $N = \{1, 2, 3, 4, \dots, n\}$ is a finite collection of participants. A subset of N denotes a coalition, and the collection of all coalitions is denoted by 2^N . $\nu: 2^N \rightarrow \mathbb{R}$ is a real-valued characteristic function with $\nu(\emptyset) = 0$. The real number $\nu(S)$ is referred to as the value of the coalition S . The relevance of this is that when the coalition S , which is a subset of N , agrees to form a coalition, then the coalition can generate a total of $\nu(S)$ monetary units. It should be noted that such an output is unaffected by the actions of players who are not part of S . In this way, the units of each coalition can be defined as a single value, $\nu(S)$, which represents the amount of utility (such as money and other kinds of transferable utility) that a specific set of S can generate through cooperation among its members.

As interpreted here, a cooperative game is sometimes called a profit game. Therefore, there is a distinct point of convergence between the objectives of cooperative game theory and transnational agricultural investment business. Regarding the particular issue of fair division in the context of OFI, a set of issues can vary and be neatly codified as a question

in the cooperative game framework. Small-scale farmland, the full potential resource, is pooled, centralized, and then transferred to the overseas investors' hand in a modified form. The main motivation behind the cooperative strategy is the potential for greater value derived from the land managed by foreign investors, in contrast to the asset initially contributed by local landowners to the pool. Due to the economic attributes of land, coalitions among nations facilitate the exchange of technology and the implementation of more productive agricultural techniques. Furthermore, countries that are part of a coalition can frequently achieve more considerable benefits than those solo producers outside a coalition.

The fundamental issue at hand is the extent to which the apportionment of agricultural business to be repatriated to host countries accords with a commonly accepted or widely agreed-upon understanding of what would be considered a “fair division”. In previous studies of fair division, the number of participants in a game was predetermined [45]. The cooperative game theory offers a range of strategies to address division problems. However, attaining equity in a coalition is a challenging task and has been a significant theoretical quandary in the field of game theory [46]. The Shapley value, introduced by Shapley [32], is defined by its fairness. This approach allows us to theorize and predict the behavior of each player when confronted with a coalition activity that must be divided among them relative to their marginal contribution to the coalition.

3.2. Core

The core, which combines the property of Pareto efficiency with individual rationality, holds significant importance in the realm of cooperative game solutions [44]. As previously stated, if all participants in a game choose to collaborate to maximize their profits, this raises a fundamental challenge regarding the allocation of rewards among them. If certain members of the grand coalition express opposition to the planned distribution, they may withdraw from the alliance or establish an alternative coalition. A core allocation is predicated on the premise that all participants will gain more profit in the grand coalition. In this respect, the concept of the core is similar to the Nash equilibrium, where taking a collective action will make them better off. An example of the core conception applied to a three-person cooperative game is shown in Figure 1, where the red part in the picture indicates the core of the game, and the labels denote coordinates in $\mathbb{R}^3$.

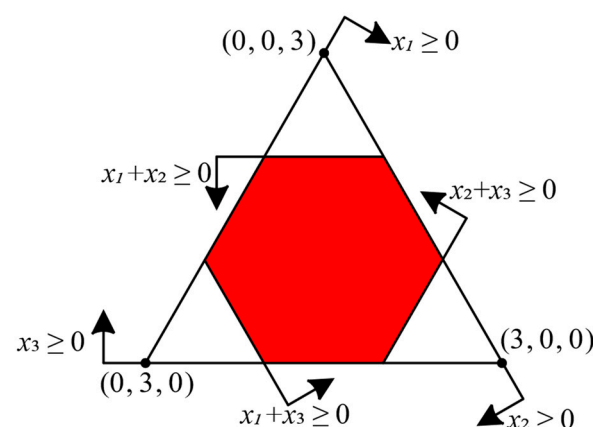


Figure 1. The core of the game under the conditions: $v(\{1\}) = v(\{2\}) = v(\{3\}) = 0$, $v(\{1, 2\}) = v(\{1, 3\}) = v(\{2, 3\}) = 1$, and $v(\{1, 2, 3\}) = 3$. Six inequalities constitute the core constraint conditions.

Cooperative game theory defines the core concept as a set of potential outcomes that represent the value of a coalition, rather than a single solution. Given a particular way of

forming the grand coalition, the marginal contribution of a participant is the increase in the coalition's value when that participant joins those who came before them. The marginal contribution reflects the significance of the player's role in the overall collaboration. A natural question here is what payoff a can player reasonably expect from their cooperation. In the subsequent section, we present the Shapley value, an axiomatic approach to measure the marginal contribution of each player.

3.3. Shapley Value

The expression of the Shapley value for each player is calculated as follows:

$$\varphi_i(v) = \sum_{S \subseteq N \setminus \{i\}} \frac{(S-1)!(N-S)!}{N!} (v(S) - v(S-i))$$

where $\varphi_i(v)$ represents the Shapley value of player i , $\varphi = (\varphi_1(v), \varphi_2(v), \varphi_3(v) \dots \varphi_i(v))$ is the benefit-sharing vector for each player, $|N|$ indicates the total number of participants, and $S \subseteq N$ is a coalition of size $|S|$. As mentioned above, $v(S)$ denotes the worth of the coalition S , also known as the expected sum value of benefit sharing for all members in a specific coalition S . $v(S-i)$ indicates the sum value of the coalition when player i is not in coalition S . Thus, the marginal contribution of player i can be measured by $v(S) - v(S-i)$ in coalition S , where all coalitions of size S that include player i are considered.

Each coalitional game is assigned an imputation, representing the anticipated payout for each player involved in the game. For its fairness characteristic and axiomatic concept, the Shapley value is a crucial approach to solving cooperative games that yield a single value. In addition, the Shapley value method has some desirable properties [9]. (1) Additivity property requires that the total benefits that players expect to receive are distributed among all the members of the coalition, implying $\sum_{i \in N} \varphi_i(N; v) = v(N)$. (2) Symmetry means non-discrimination, as it requires that participants who have equal positions within a coalition should receive the same utilities, implying $v(S \cup \{i\}) = v(S \cup \{j\})$ for every coalition $S \subseteq N \setminus \{i, j\}$. A solution concept φ satisfies symmetry for each pair of players i and j in a game who are symmetric, implying $\varphi_i(N, v) = \varphi_j(N, v)$. (3) A null player states that if a player does not contribute any further to whatever coalition they join, they will not derive any positive sum, implying $\varphi_i(v) = 0$ for $v(S) = v(S \cup \{i\})$.

4. Results and Discussion

4.1. Case Study

Promoting international cooperation in the agricultural sector will enable more efficient crop yields, alleviate hunger crises, and contribute to addressing global food security issues. Proponents of OFI contend that host countries have the potential to gain advantages from overseas direct investment in farmland [47,48]. Due to the expansive increase in overseas investment in agriculture and the worldwide land rush, some countries that have a surplus of capital but a scarcity of food, including Japan, South Korea, the Gulf countries, and China, have progressively engaged in global land acquisition [42]. Since the 1980s, the process of industrialization and urbanization in China has led to a significant influx of people from rural areas to cities. This migration has contributed to a decrease in farmland and resulted in food insecurity in most Chinese cities [24,49]. Within the framework of globalization, the Chinese government proposed the initiative of the "Belt and Road", trying to encourage transnational cooperation. This initiative, an international agricultural cooperation program, has emerged as a pivotal conduit through which China disseminates opportunities for agricultural development to countries along the "Belt and Road". This initiative is poised to play a critical role in addressing global hunger and poverty while

simultaneously fostering global food security. Chinese entities contribute by introducing agricultural varieties, advanced technology, and expertise to local regions. This leads to enhancements in local agricultural production methods and yields, as well as an increase in employment opportunities and income for those in poverty. We chose China and typical host countries in Southeast Asia for our case study since Chinese corporations have made significant land investments worldwide.

A case study was selected from Southern Asia for several reasons. First, Southeast Asia, with the richest arable land resource, is the main production and supply area for global agricultural products [50]. Based on the statistics provided by Land Matrix (<http://landmatrix.org/>, accessed on 25 February 2025), the overall contract size of OFI exceeds 6.3 million hectares in Southeast Asia. Secondly, developing countries in Southeast Asia deal with similar issues like low agricultural productivity, lack of effective investment, and inadequate infrastructure. Overseas investment in the agricultural sector is crucial to solving the problem of poverty reduction and food safety [51]. Finally, “the Belt and Road” is an integrated network of routes that passes through Southern Asia, connects China, and makes it easier for foreign investors to engage in international trade and agricultural cooperation. There seems to be a great deal of room for cooperation between China and the nations of Southeast Asia to jointly guarantee food security. Nonetheless, foreign land purchases are typically denounced as “land grabs” [12,52]. In an attempt to safeguard their own food supply, overseas investors pillaged resources, which had an even greater effect on host nations [53]. A number of factors influence the success and sustainability of OFI collaboration, but one of the most important is the benefit reallocation strategy that coalition members adopt. Thus, the primary challenge in OFI now lies in how to divide benefits fairly.

As noted above, one of the main problems is chronic underinvestment due to the lack of transnational cooperation. The world still has unsolved problems with hunger and poverty. To guarantee food security and livelihood sustainability, it is crucial for all parties concerned to conduct bilateral and multilateral agricultural trade and investment [5,51]. A major dispute among the overseas investor and host country revolves around the fair division of profits generated by farming cooperation between two or more countries. The Shapley value can be employed as an equitable allocation method in such situations.

A set of individual participants were selected for further analysis, where *Player 1* represents China, *Player 2* represents Vietnam, and *Player 3* represents Laos. Figure 2 shows the average production of the three countries from 2009 to 2021. The amount of Chinese production had a tendency to increase and peaked in 2021 with 6.3 tons/hm². Similarly, a gradually increasing tendency in the amount of average production in Vietnam has been seen, except in 2016 and 2017. In addition, the production in Laos fluctuated between 3.8 and 4.6 tons/hm². It is clear that the agricultural production levels in the latter two countries have been relatively low, and there is still tremendous space for growth. The operation of the cooperative game associated with the host countries is as follows. In the case of non-cooperation, the host country will farm its arable land without overseas investment. As previously explained, the additional revenue from the improvement in farming efficiency and yield is motivated by overseas investment and technology.

The computation of the Shapley values is straightforward and understandable due to the limited number of players in the example. In this context, we calculate the Shapley value to explain that a fair division assignment can be found with respect to OFI sharing among stakeholders, and we compare the results under different conditions to show their validity. These players may agree to join the coalition, which implies that they accept participating in certain activities, e.g., welcome or advocate overseas investment in the agricultural sector. Such an activity means incurring the cost of production. However, it

also yields tangible benefits, such as making use of vacant land, increasing agricultural production, reducing food costs, and inevitably reaping economic advantages [10,42].

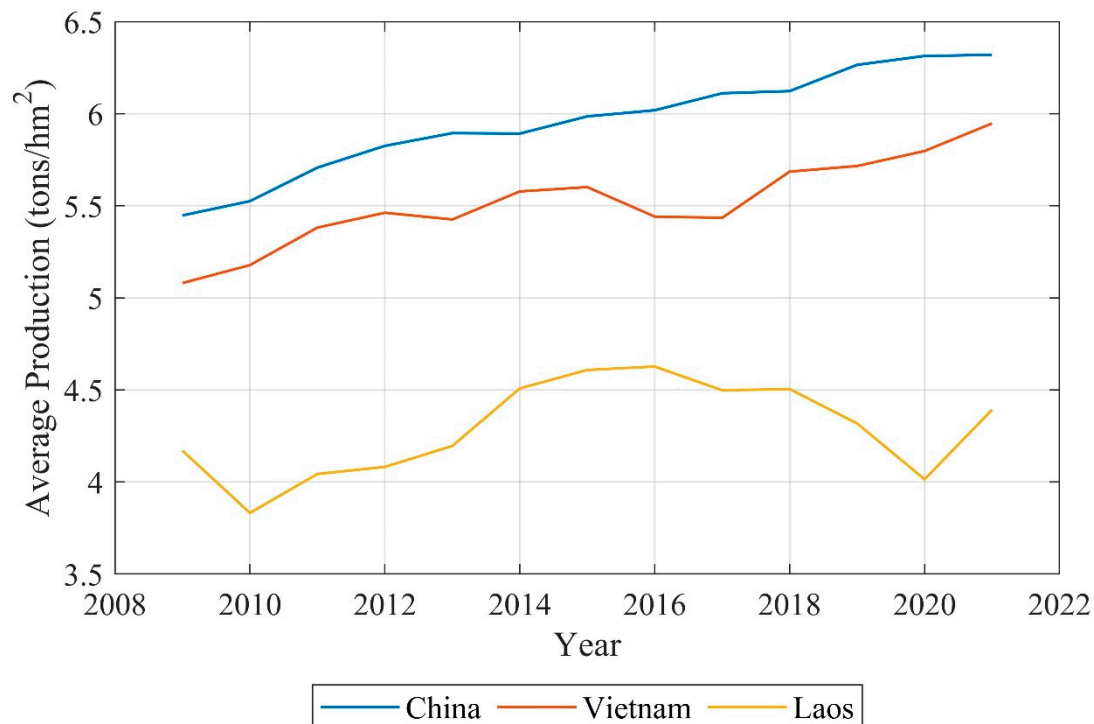


Figure 2. The agricultural productivity of China, Vietnam, and Laos. These data are freely available from the World Bank on its website (<https://data.worldbank.org/>, accessed on 25 February 2025).

There are five possible outcomes in the three-person cooperative game, called scenarios in Table 1. Specifically, all of the farmlands in the three countries are developed separately in scenario A. In scenario B, only *player 1* and *player 2* form alliances, leaving out *player 3*. Players can share technology by forming alliances, which allows them to produce with more efficient machinery. Taking Scenarios A and B as examples, each player has its own production level, which reflects the average production per farmland. According to the data collected from Figure 2, *player 1* possess a higher technology level than *player 2*. Once *player 1* and *player 2* form an alliance, they share technology and produce with the most efficient technology. It is similar in Scenario E, where *players 1, 2, and 3* share the highest level of 5.96, leading to greater benefits obtained by collaboration than those produced independently. In practice, overseas investors who possess substantial financial resources and advanced technological capabilities seek to establish collaborative relationships in underdeveloped regions. The economic ramifications of this phenomenon are evident. Regions characterized by underdeveloped productivity stand to benefit from enhancing their production efficiency through strategic collaboration with overseas investors. As a result, farmland within the alliance frequently yields larger profits than independently produced land outside the alliance. Scenarios C and D are similar to scenario B. Lastly, scenario E represents the grand coalition, in which the three countries work together to expand their agricultural areas. These scenarios lead to varying levels of development for farmland production, depending on whether they are developed separately or in different combinations of farmland acquisition. The Shapley value technique in a cooperative setting presumes that all combinations have an equal probability of occurring [54].

Table 1. Different coalitions in three-player games under all possible conditions.

Scenario	A	B	C	D	E
Coalition	$\{1\}$ $\{2\}$ $\{3\}$	$\{1, 2\}$ $\{3\}$	$\{1, 3\}$ $\{2\}$	$\{1\}$ $\{2, 3\}$	$\{1, 2, 3\}$
Target area (hm ²)	2.8×10^5 3.9×10^5 4.5×10^5	6.7×10^5 4.5×10^5	7.3×10^5 3.9×10^5	2.8×10^5 8.3×10^5	1.1×10^6
Production level (tons/hm ²)	5.96 4.29 5.52	5.96 5.52	5.96 4.29	5.96 5.52	5.96

The target area indicates the area of farmland invested in by overseas investors (Land Matrix Database: <https://landmatrix.org/>, accessed on 25 February 2025). The production level refers to the average production calculated from 2009 to 2021 (Figure 2).

Here, only the average production is considered, while the costs of labor, seed, and other costs are not taken into account. This strategy makes sense because crop yields at harvest time are directly correlated with output levels and have a significant impact on the division scheme's outcomes. Transnational cooperation in the agricultural sector may result in a change in the primary body of benefits, with participants in a coalition potentially receiving more advantages. The measurement formula for each benefit is

$$\text{Farmland benefit value} = \text{Total area} \times \text{Production level}$$

where the farmland benefit value represents the value of agricultural production, total area indicates the land acquired by the overseas investor, and production level represents the production level of farmland for different coalitions. We allocate specific payoffs to each coalition, which is also referred to as the characteristic function in game theory terminology, denoted by $v(S)$. Thus, the benefits (measured as gross cereal production) for each coalition are

$$\begin{aligned} v(\emptyset) &= 0, v(\{1\}) = 1.7 \times 10^6, v(\{2\}) = 1.7 \times 10^6, v(\{3\}) = 2.4 \times 10^6; \\ v(\{1, 2\}) &= 4.0 \times 10^6, v(\{1, 3\}) = 4.3 \times 10^6, v(\{2, 3\}) = 4.6 \times 10^6; \\ v(\{1, 2, 3\}) &= 6.6 \times 10^6. \end{aligned}$$

Clearly, this game is essential. This means $v(N) > \sum_{i=1}^n v(\{i\})$, indicating that the gains of the grand coalition exceed the total benefits of each individual participant:

$$v(\{1, 2, 3\}) \geq v(\{1\}) + v(\{2\}) + v(\{3\})$$

In addition, the game is superadditive, demonstrating that $v(S \cup T) \geq v(S) + v(T)$, $\forall S, T \subset N$, and $v(S) \cap v(T) = \emptyset$, where S and T are two separate subsets of N , indicating that the benefit of a specific coalition is greater than the combined benefits of its individual subsets:

$$\begin{aligned} v(\{1, 2\}) &\geq v(\{1\}) + v(\{2\}); \\ v(\{1, 3\}) &\geq v(\{1\}) + v(\{3\}); \\ v(\{2, 3\}) &\geq v(\{2\}) + v(\{3\}); \\ v(\{1, 2, 3\}) &\geq v(\{1, 2\}) + v(\{3\}) \\ v(\{1, 2, 3\}) &\geq v(\{1, 3\}) + v(\{2\}); \end{aligned}$$

$$\nu(\{1, 2, 3\}) \geq \nu(\{2, 3\}) + \nu(\{1\}).$$

Otherwise, this game is non-convex, suggesting that $\nu(S \cup T) + \nu(S \cap T) \geq \nu(S) + \nu(T)$ and $\forall S, T \subset N$, where S and T are two joint subsets of N :

$$\nu(\{1, 2\}) \geq \nu(\{1\}) + \nu(\{2\});$$

$$\nu(\{1, 3\}) \geq \nu(\{1\}) + \nu(\{3\});$$

$$\nu(\{2, 3\}) \geq \nu(\{2\}) + \nu(\{3\});$$

$$\nu(\{1, 2, 3\}) \geq \nu(\{1, 2\}) + \nu(\{3\});$$

$$\nu(\{1, 2, 3\}) \geq \nu(\{1, 3\}) + \nu(\{2\});$$

$$\nu(\{1, 2, 3\}) \geq \nu(\{2, 3\}) + \nu(\{1\});$$

$$\nu(\{1, 2, 3\}) + \nu(\{1\}) \geq \nu(\{1, 2\}) + \nu(\{1, 3\});$$

$$\nu(\{1, 2, 3\}) + \nu(\{3\}) \geq \nu(\{1, 3\}) + \nu(\{2, 3\}).$$

but not for the coalition:

$$\nu(\{1, 2, 3\}) + \nu(\{2\}) \not\geq \nu(\{1, 2\}) + \nu(\{2, 3\}).$$

The computation of the Shapley value entails evaluating the marginal contribution of each player, which is represented as $[\nu(S) - \nu(S \setminus \{i\})]$. As an example, there are several options for *Player 1*. *Player 1* may decide to manage the farmland individually (Scenarios A and D), form an alliance of two (Scenarios B and C), or cooperate together (Scenario E). If *Player 1* decides to cooperate with another player, there are two alternatives: cooperating with *Player 2* or *Player 3*, where the probability of the two alternatives is the same. The Shapley value for *player 1*, $\varphi_1(\nu)$, is then calculated considering each possible coalition (Table 2).

Table 2. Initial benefit sharing scheme for *Player 1*.

S	1	1 + 2	1 + 3	1 + 2 + 3
$\nu(S)$	1.7×10^6	4.0×10^6	4.3×10^6	6.6×10^6
$\nu(S \setminus \{1\})$	0	1.7×10^6	2.5×10^6	4.6×10^6
$ S $	1	2	2	3
$w(S)$	1/3	1/6	1/6	1/3
$w(S)[\nu(S) - \nu(S \setminus \{1\})]$	5.6×10^5	3.9×10^5	3.1×10^5	6.8×10^5
$\varphi_1(\nu)$	$5.6 \times 10^5 + 3.9 \times 10^5 + 3.1 \times 10^5 + 6.8 \times 10^5 = 1.9 \times 10^6$			

Similarly, the result of the Shapley value for *Player 2*, $\varphi_2(\nu)$, is shown in Table 3.

Table 3. Initial benefit sharing scheme for *Player 2*.

S	2	1 + 2	2 + 3	1 + 2 + 3
$\nu(S)$	1.7×10^6	4.0×10^6	4.6×10^6	6.6×10^6
$\nu(S \setminus \{2\})$	0	1.7×10^6	2.5×10^6	4.3×10^6
$ S $	1	2	2	3
$w(S)$	1/3	1/6	1/6	1/3
$w(S)[\nu(S) - \nu(S \setminus \{2\})]$	5.5×10^5	3.8×10^5	3.5×10^5	7.7×10^5
$\varphi_2(\nu)$	$5.5 \times 10^5 + 3.8 \times 10^5 + 3.5 \times 10^5 + 7.7 \times 10^5 = 2.1 \times 10^6$			

Finally, the result of the Shapley value for *Player 3*, $\varphi_3(\nu)$, is shown in Table 4.

Table 4. Initial benefit sharing scheme for *Player 3*.

S	3	1 + 3	2 + 3	1 + 2 + 3
$v(S)$	2.5×10^6	4.3×10^6	4.6×10^6	6.6×10^6
$v(S \setminus \{3\})$	0	1.7×10^6	1.7×10^6	4.0×10^6
$ S $	1	2	2	3
$w(S)$	1/3	1/6	1/6	1/3
$w(S)[v(S) - v(S \setminus \{3\})]$	8.2×10^5	4.4×10^5	4.9×10^5	8.8×10^5
$\varphi_3(v)$	$8.2 \times 10^5 + 4.4 \times 10^5 + 4.9 \times 10^5 + 8.8 \times 10^5 = 2.6 \times 10^6$			

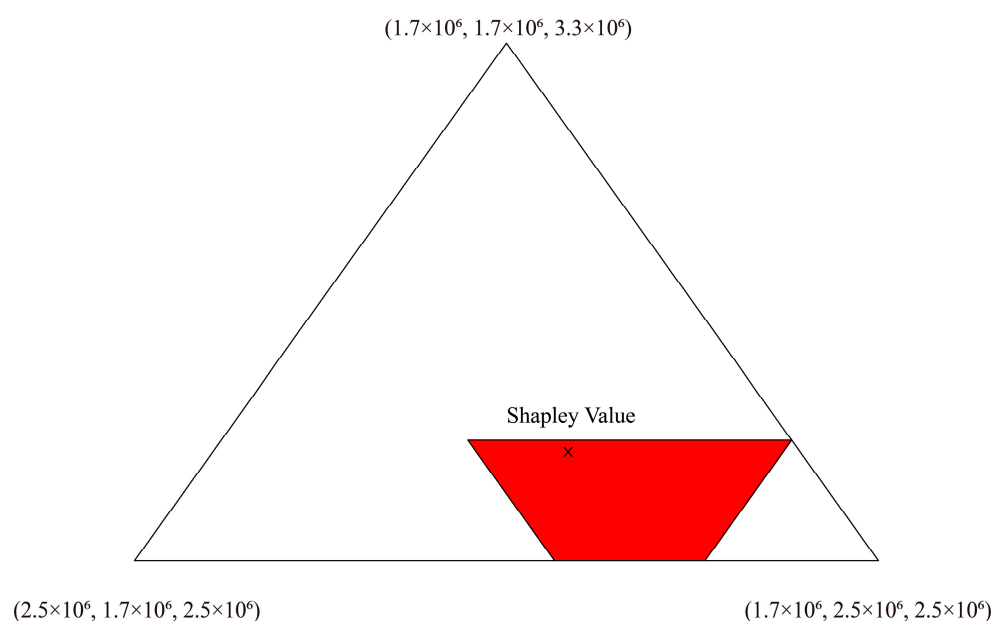
In this case, the core is non-empty. However, the Shapley value might lie outside the boundaries of the core, which is seen as an extremely undesirable result. The constraints of the core condition in the current study can be expressed as

$$\varphi_1(v) \geq 1.7 \times 10^6, \varphi_2(v) \geq 1.7 \times 10^6, \varphi_3(v) \geq 2.5 \times 10^6$$

$$\varphi_1(v) + \varphi_2(v) \geq 4.0 \times 10^6, \varphi_1(v) + \varphi_3(v) \geq 4.3 \times 10^6, \varphi_2(v) + \varphi_3(v) \geq 4.6 \times 10^6;$$

$$\varphi_1(v) + \varphi_2(v) + \varphi_3(v) \geq 6.6 \times 10^6$$

Clearly, the Shapley value in the present case fulfills these constraints. The Shapley solution is computed efficiently, and the properties of core conditions are evaluated using the R 4.4.3 Package “CoopGame 0.2.2”. Figure 3 shows the core condition, and the Shapley value for this game is part of the core as a graphic output. As a result, the Shapley model of OFI is feasible. This result indicates that the Shapley allocation guarantees each player (the host countries and overseas investors) at least the same benefits as those in the non-cooperative condition. That is, the Shapley allocation method provides incentives to cooperate. In this way, the extra benefits obtained from cooperation are divided fairly. If we compare the difference between the Shapley value and the benefits without cooperation for each player, it shows that the difference is the same for all stakeholders.

**Figure 3.** The core condition in the present case and the Shapley value.

4.2. Discussion

In the context of degraded soil and collapsing agricultural ecosystems, emerging nations are seeing a decline in grain output, putting women and children at risk of hunger

and poverty [55]. Long-term recipients of international humanitarian aid have severe issues with food supply, and their citizens typically consume less nutrients overall. In this sense, international food aid cannot fundamentally solve regional hunger problems [56]. A practical and feasible approach is to build agricultural infrastructure and promote agricultural technology in developing countries. Nevertheless, the primary factors responsible for the lack of investment in the agricultural sector are poor profit margins and high levels of risk. It appears that domestic investors lack sufficient economic incentives to invest in agricultural infrastructure [25,33]. Therefore, solving global food insecurity through transnational cooperation remains an urgent issue in the 21st century, and OFI provides an economically feasible solution for this project.

The main limitation of the arguments in favor of OFI rests essentially on the fair compensation to the local population [25,30]. To advance fair division in OFI, this study proposes a possible cooperative game framework. The Shapley value is directly proportional to the number of countries in the alliance, with greater numbers resulting in greater benefits for the joining countries. The greater the amount of farmland and capital, the higher the Shapley value, and the greater the benefits obtained from joining the alliance. This, in turn, renders the achievement of OFI cooperation more feasible. The technological disparity in the study area suggests that the adoption of progressive technologies by alliance members will enhance the technological capabilities of the alliance and elevate the Shapley value. The alliance's stability and formation are contingent upon the accruing benefits received by the participating countries as a result of cooperation. From an economic production perspective, the feasibility of OFI cooperation is substantiated.

Of course, there are some limitations to be addressed in the future. Although technology transfer and job possibilities may bring certain advantages, a significant portion of indigenous people viewed the overall impacts of OFI as unfavorable, pointing out issues such as water plundering, land conflicts, and unsatisfactory working conditions [36,57,58]. In many cases, the host government will expropriate the land rights of residents in the target area to attract foreign investors [18]. Overseas investors in countries lagging behind in development can take possession of land on long-term leases at very low prices, which greatly fosters speculative leasing behavior. Evidence suggests that many land deals are completed without subsequent productive investment, with only 20% of the announced investment projects actually engaging in agricultural production activities. In this way, OFI or official-led leasing has, to some extent, infringed on the customary rights and interests long held by the original inhabitants, thereby affecting their livelihoods.

Another concern of OFI is the ecological destruction during the process of transnational land acquisition. In past decades, the global land rush has been connected with significant changes in land use systems, associated with accelerated deforestation and a heightened risk of biodiversity loss [15,57]. OFI has prompted a transformation in smallholder agriculture, leading to its displacement by large-scale agriculture. However, the resulting environmental costs are highly contradictory. Multiple existing cases provide evidence that OFI practice will have deep ecological impacts on ecosystem functioning and land use change. To mitigate potential environmental repercussions, it is necessary to develop methods that address the extensive global occurrence of OFI and the ongoing expansion of areas affected by the global land rush.

As for the method used in our study, we acknowledge some inadequacies of the Shapley value. First, the development of globalization has resulted in the establishment of close connections between nations in various domains, including the economic, trade, political, and cultural spheres. In the process of constructing the model, reasonable economic assumptions were made, thereby simplifying the relationship of mutual influence between countries. Subsequent research endeavors may involve the refinement of the cooperative

game, drawing upon empirical data derived from actual geopolitical networks. Second, the establishment of international cooperation will precipitate a shift in the price of arable land, which will be influenced by the prevailing supply and demand relationship. In practice, the decision-making process involves complex negotiation and other heterogeneous factors that are ignored by our model, which can be discussed in the future. Third, due to the limited availability of OFI data, the case simulation only selected data from three countries for testing. In the future, further research will be strengthened by incorporating empirical evidence of ongoing cooperative practice.

From the perspective of sustainable production, transnational cooperation in the agricultural sector is practically feasible. The Shapley value method provides a relatively equitable scheme for distributing benefits. In practice, it could be more difficult to apply the Shapley value to compute the allocation scheme, because stakeholders should bargain among themselves to achieve agreements. In general, the current pattern of benefit distribution puts the residents of the invested areas in a disadvantaged position. The indigenous people of the host countries not only have unstable channels of income, a single income mode, and a low level of income but also have to bear the “negative costs” of ecological degradation, which have led to frequent social conflicts and pose a threat to the security and stability of the region. Therefore, a revision of the Shapley value should be considered in the future to take into account the vitality of the local people, on the one hand, and to incorporate environmental governance costs into the calculation of production cost, on the other hand.

In addition, it seems that cooperation between stakeholders in the development of OFI has gone far beyond the economic sphere, and it is crucial to examine a harmonious distribution of ecological, cultural, and social aspects. For this reason, a series of treaties and regulations are needed to regulate the behavior of interest, to ensure that the transnational cooperation in farmland is carried out in an orderly manner. In practice, the Principles for Responsible Investment in Agriculture and Food Systems were approved by the Committee on World Food Security well before 2014. Typical established instruments have provided guidelines to enhance food security and eco-friendly development by improving secure access to farmland. A major challenge is the lack of unified standards for fair division and the low cost of transnational collaboration through this market.

Clearly, the previous efforts are not enough. Research on OFI is currently incomplete, and the fair division scheme in OFI has been poorly investigated. An established structure for the development and management of global land acquisition is currently lacking, which, to some extent, hinders international cooperation due to the absence of consensus. Responsible investment in agriculture is intended to prioritize the enhancement in food security, ensuring the sustainable utilization of natural resources, fostering regional development, and finally, achieving a fair distribution of benefits. OFI prioritizes enhancing production efficiency but overlooks the environmental costs and division issues related to land use and food production. The primary obstacle confronting rural development in developing nations is the latter, which is also the primary cause of the widespread criticism of OFI.

5. Conclusions

Global food insecurity is currently one of the most urgent and significant challenges we face in the present and will face in the future. While OFI has gradually developed into an effective way to improve agricultural productivity by providing financial support and information services, it faces the issue of fair division of benefits. In this study, we have considered the problem of fair division and the possibility of cooperation among host landowners and overseas investors to maximize their benefits within a cooperative game framework. When technology and information are shared among host countries and

overseas investors, productivity can be improved, which generates additional profits. This article proposes a fair way of allocating the total benefits between host landowners and overseas investors that also incentivizes such transnational cooperation.

The authors believe that the Shapley value can be used based on cooperative game theory to realize fair division in the OFI. Overall, this study contributes to the existing literature by employing the Shapley value model to frame the benefit reallocation scheme. From the standpoint of cooperative game theory, OFI may offer participants higher benefits, which can be regarded as a vital motivation for collaborators. Cooperation to improve farmland yields through technology and capital transfer is achievable in practice. However, such a fair distribution scheme is only possible in an appropriate institutional setting. OFI is a transnational investment activity involving multiple parties, and its normal production requires the comprehensive utilization of multiple production factors. Therefore, it is helpful to determine the final distribution ratio of each party according to the size of its contribution. In addition, it is important for OFI to not only focus on increasing regional food production but also emphasize the enhancement of the well-being of local inhabitants and the protection of the ecological environment. This will enable an agreement to be reached regarding investment in agricultural land. Non-equilibrium distributional schemes do not enhance the welfare of any party involved, and as the duration of bargaining and negotiation increases, each party experiences a loss.

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