A game theory model to explore the role of cooperation and diversity in community food security: the case of Southern Malawi.

Stefano Balbi[1,2,*], Unai Alvarez-Rodriguez[1,3], Vito Latora[3,4,5], Alberto Antonioni[6], Ferdinando Villa[1,2]

[1] Basque Centre for Climate Change (BC3), Sede Building, Campus EHU/UPV, Leioa, Bizkaia, Spain. stefano.balbi@bc3reserch.org, unai.alvarez@bc3research.org, ferdinando.villa@bc3research.org
[2] IKERBASQUE, Basque Foundation for Science, Bilbao, Bizkaia, Spain.
[3] School of Mathematical Sciences, Queen Mary University of London, London E1 4NS, UK. v.latora@qmul.ac.uk
[4] Dipartimento di Fisica ed Astronomia, Università di Catania and INFN, I-95123 Catania, Italy.
[5] The Alan Turing Institute, The British Library, London, NW1 2DB, UK.
[6] Grupo Interdisciplinar de Sistemas Complejos (GISC), Departamento de Matemáticas, Universidad Carlos III de Madrid, E-28911, Leganés, Madrid, Spain. alberto.antonioni@gmail.com
* Corresponding author

Abstract

The Sustainable Development Goals aim at ending food insecurity by 2030. Therefore, civil society needs to understand the inherent complexities of both socio-economic and ecological dynamics and their interdependencies. In particular, the behavioural dynamics that underpin human agents are crucial in driving the final outcomes in terms of community food security and require further attention. Using household behaviour within a rural village of Southern Malawi as an example, we describe a game theory model representing cropping strategies: (1) cooperation, as driven by other-regarding preferences, and (2) conformation, the tendency to converge to similar crop planting choices as opposed to differentiation (and thus crop diversity). We find that the latter plays a crucial role in driving the system towards successful strategies: how individuals relate to social norms has greater effect. Cooperation is only necessary for community success when the community converges on crop planting choices. On the contrary, differentiation, the affirmation of the individual unique identity, can succeed with or without cooperation. We further elaborate on the idea that community level sustainability can be reached through different pathways, which might require food exchange mechanisms within and beyond the system boundaries.

Keywords

human behaviour; game theory, social networks, diversity, social-ecological systems, food security.

Length of Manuscript: 6100 words and 5 figures and 1 table.

1. Introduction

Food provisioning is a key challenge of coupled human-natural systems. The Sustainable Development Goals (SDGs) adopted by the United Nations have set a clear target to end food insecurity by 2030 (UN 2015a). In order to achieve this target understanding the inherent complexities of both socio-economic and ecological dynamics, and their mutual feedbacks across scales is crucial (Ostrom 2008). While agro-ecological dynamics are well explored in the literature (e.g. Chappell and LaValle 2011), the behavioural dynamics that underpin human agents require more research to understand how they drive community food security, especially in rural regions of the Global South.

Using household crop planting choices within a rural village as an example, we introduce a behavioural compass based on two dimensions: (1) cooperation, the degree to which individual success depends on neighbours' success due to other-regarding preferences, which in turn captures a community scale objective function, and (2) conformation, the tendency to converge towards similar crop planting choices as opposed to differentiation, and as a consequence, crop diversity. We argue that by acknowledging the interplay among these two dimensions in shaping household cropping strategy, a rural agricultural system can better reorganize, spontaneously or by means of policy interventions, to improve food security at the community level.

In the following paragraphs we explain the compass axes, used as a reference system to characterize household behaviour and show how the compass applies to the selected case study: a rural village of Southern Malawi. In Methods, we describe the context and the data used for the application and the mathematical formalization of the model. We also describe its behaviour as we change the main household parameters (other-regarding preferences and homophily) within their interval of reference. In Results, we assess the model performance when the game parameters (number of households, number of crops and network topology) are set to match the case study characteristics, deriving the household behaviour that delivers the best outcomes. In Discussion, we elaborate on the implications of the model findings for the community food security. Finally, we conclude with the key messages of this study.

Inspired by the political compass of Maddox and Lilie (1984) and Lester (1994), we refer to a behavioural compass (Fig. 1), a four by four grid where the horizontal axis represents economic behaviour and displays competition at its left side and full cooperation at its right side, while the vertical axis represents personal behaviour and displays differentiation at the bottom end and conformation at its top end.

Economic behaviour describes how the individual relates to the others for the purpose of achieving resources, including consumption and utilisation of natural resources. Cooperation can be understood as the process of acting in coordination with others to maximise individual or mutual benefit (Perc et al. 2017). Competition arises when at least two parties strive for a goal that cannot be shared, or is desired individually but not in sharing.

Personal behaviour describes how individual beliefs and values relate to social norms. Conformation is the process of matching individual behaviour with the dominant social norms, while differentiation—as in psychological differentiation (Witkin et al. 1974)—is the process of affirming an individual unique identity against social norms. Thus, the higher differentiation, the higher the diversity of behaviours within the system.

In an early example of a similar approach, Deutsch (1949) identifies three types of "goal structures on achievement": cooperative, competitive and individualistic. Cooperation and competition have been extensively researched in ecology and economics (game theory, in particular: see Fehr and Fischbacher 2002) as individual operating modes (from the seminal work of Axelrod and Hamilton 1981 to more recent reviews, such as Perc et al. 2017). Differentiation and conformation belong to the domain of behavioural and experimental methods in psychology and economics and, in the context of this study, are particularly close to the research on how social norms and the framing of options influence individual behaviour, with significant repercussions for human cooperation and natural resource exploitation (Kahneman 2011).

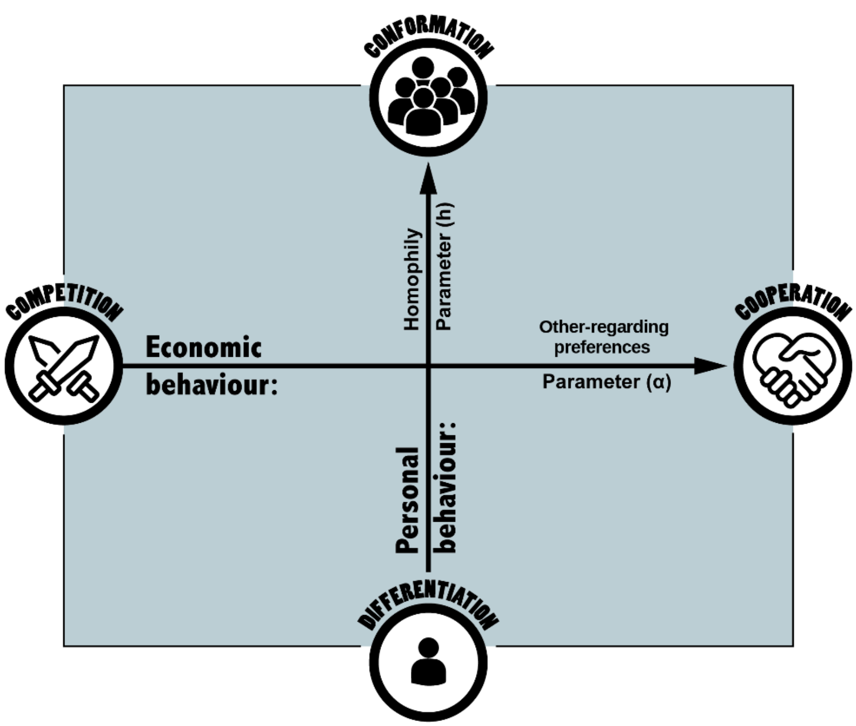

Fig. 1 The behavioural compass

2. Methods

In this article, we refer to community food security as an emergent property of household food security, which is a consequence of how households interact, acquire and utilise assets, including natural resources (Chambers and Conway 1991). In most cases, the livelihoods of rural households remain largely dependent on agriculture. This article explores data of a rural region located in the southern part of Malawi, a small, landlocked African country home to approximately 15 million people. More than 90% of the rural population are smallholder farmers, responsible for cultivating plots with an average size of just 0.8 hectares (NSO 2012). Maize is the socially preferred crop among smallholders and the main staple diet of the population (NSO 2012). According to Chinsinga and Chasukwa (2012), although over 97% of smallholder farmers grow maize, only 10% are net sellers and up to 60% are net buyers.

Typically, most of the households within a rural village are at least acquainted with each other and it is common practice to exchange on-farm labour and food donations in periods of need (Dobbie et al. 2018). Similar dynamics have been witnessed in rural settings around the globe (Patel 2009) including: sharing of unused ingredients that would otherwise be trashed, sharing of knowledge about farming practices, good nutrition and recipes, invitations to join meals, exchange of seeds and food commodities to increase diversity of diet, exchange of portions of meals in different periods in time to cushion temporary scarcity (i.e. food banking). In Malawi, this system of informal social exchanges coexists with a market-oriented structure that heavily relies on local and regional food markets for the integration and redistribution of food commodities, as a consequence of the liberalisation reforms promoted by the International Monetary Fund and the World Bank (Dorward and Kydd 2004).

2.1 The case of food security in Southern Malawi

In Malawi over 50% of the population live on less than one US dollar a day and the proportion of ultra-poor people (defined as the proportion of population below the minimum level of dietary energy requirement) is highest within Southern Malawi at approximately 34.2% (Gondwe 2014). Food security is particularly problematic in rural areas where agriculture is primarily rain-fed, leaving smallholders vulnerable to climatic shocks (Sahley et al. 2005). A single rainy (growing) season, between the months of November and March, is followed by a dry season from April to October. Only a limited number of farming households with access to *dimba* fields of the valleys located at the source of streams, creeks, or rivers may take advantage of residual moisture and extend cultivation beyond the end of the rains (Orr et al. 2009). High population densities, small average plot size and poor soil quality further increase food insecurity. The rural population is anticipated to grow from approximately 8.4 million in 1990 to almost 20 million by 2030 (UN 2015b) and this growth will have wide ranging impacts upon land and labour availability as well as market prices and productivity. Additional exogenous trends such as soil degradation and climate change further compound food insecurity (Schmidhuber and Tubiello 2007).

Indeed, food security is multidimensional issue (Connolly-Boutin and Smit 2016). A total of four dimensions are recognized under the “four pillars” framework—created by FAO and operationalised for modelling purposes in Dobbie and Balbi (2017)—including food availability, access, utilisation and stability. The production of food is related primarily to food *availability* (Headey and Ecker 2013). *Access* refers to the amount of food a household can produce, purchase from the market and/or derive from other means (Burchi and De Muro 2016). Households might draw upon social safety nets such as food for work programmes or adopt coping strategies like selling livestock or borrowing food (Devereux 2016). A third dimension, *utilisation*, refers to the ability of households to process accessible food. This is dependent upon the household ability to obtain sufficient quantities of fuel and clean water. Finally, *stability* dictates how robust availability, access and utilisation dimensions are to shocks and stresses over time (Burchi and De Muro 2016), such as those related to climatic and demographic change. This article focuses primarily on the first two pillars: availability and access.

In the following paragraph we present the alternative principles of the behavioural compass applied to the cropping strategies of farming households, and illustrate how the combination of these principles is relevant for understanding community food security (Fig. 1). The four storylines shown in Table 1, which describe observed household cropping behaviours in rural regions of the Global South, are synthesized from the Participatory Rural Appraisals (PRA: Schreckenberg et al. 2016) that took place in multiple villages of the Zomba Region, in Southern Malawi.

According to the *competition and conformation* storyline (Table 1), a household would maximise the yield of maize using all the available inputs subsidized by the government (e.g. hybrid maize seeds and chemical fertilizer), and sell the produce at market. This is currently the most common strategy within the villages of Southern Malawi, where liberalisation reforms have failed to the produce the intended improvements and the social norms regarding what to grow are widely and voluntarily accepted. Food preferences are key in this regard. Maize has become the main food asset in the local markets and is considered a strategic commodity. This social norm is not only detrimental in terms of diet variety and healthy nutrition, but also makes the region more at risk in the face of climate change by imposing a climate-vulnerable crop to the majority. With *cooperation and conformation* a household would plant maize and share the produce with the neighbours that have provided the labour to farm the land. This used to happen more often in the past when the farm clubs were popular, before the reforms, although mainly for cash crops. With *cooperation and differentiation* a household would maximise crop diversity choosing a mixed cropping pattern with different proportions of maize, pigeon pea, sweet potato, cassava, fruit trees, and vegetables. With *differentiation and competition* a household would maximise profit by planting cash crops, such as tobacco, peppers, or cotton. The emphasis on profit rather than on nutrients makes it a risky paradigm from a food security perspective, especially if we assume that self-sufficiency is relevant at the village level, as opportunity cost may drive agricultural entrepreneurs to invest on non-food crops beyond the social optimal level (e.g. Anderman et al. 2014).

Table 1. Behavioural compass: village food security storylines.

2nd Quadrant: Competition & Conformation The household produces the socially preferred crop, maximizing possible yield in order to have more commodity to be exchanged at the market. Seed and fertilizer subsidies influence this behaviour.	1st Quadrant: Cooperation & Conformation The household produces the socially preferred crop, after which the produce is aggregated to that of other producers belonging to a farm club, and shared equitably.
3rd Quadrant: Competition & Differentiation The household chooses a cropping pattern that maximizes income, with the objective of obtaining a more valuable commodity (diversified quality) to be exchanged at the market (e.g. cash crop).	4th Quadrant: Cooperation & Differentiation The household plants crops in order to maximize crop diversity, differentiating cropping pattern vs. its neighbours. Later food exchanges increase diet diversity.

2.2 Data and model formalization

Household-level data for a village in Southern Malawi was collected over a period of four days in July 2015 as part of the larger research project (Schreckenberg et al. 2016). Four trained Malawian enumerators used a household questionnaire to collect information on farming practices, crops planted, harvested and sold, other income generating activities, perceived food security, and socio-demographic characteristics of the households. After a village mapping exercise, in which three village representatives listed the household heads and mapped their locations, all households (N = 46) were selected (census) to participate. This same dataset was also used to calibrate an agent-based model to simulate the community food security into the future (Dobbie et al. 2018). In this study we utilize the information on the crops planted, harvested and sold, which include: maize, groundnuts, tubers, pigeon peas, peas, sorghum, beans, soy, vegetables, and cotton.

We propose a game theory model for describing the household cropping strategies. We assume that each household is able to change its main crop type, at each time step, and that there is only one planting season per year. The crop selection depends on two main factors, which describe personal and economic behaviour, as per behavioural compass. The first one is homophily, which determines the household tendency to imitate its neighbours and is therefore the parameter corresponding to the differentiation-conformation axis (i.e. personal behaviour). The second one describes other-regarding preferences, the influence of community level satisfaction in the household decision, and corresponds to the competition-cooperation axis (i.e. economic behaviour). The main rules of the game are given in the following bullet points:

- The topology of interactions is given by an initial network of *N* nodes, each node representing one household, whose connections, represented in a matrix *A* with elements a_{ij}, remain constant in time.
- Each node has a state, σ_i, which represents the household chosen main crop, and is updated asynchronously at each time step.
- The state, $\sigma_i \in \{1, S\}$, with *S* being the total number of crops, changes at each time step according to the best response mechanism. This, implies that each household tests all the possible crops and selects the one that maximizes its payoff. Crops are initialized according to a uniform distribution.
- The other-regarding preferences parameter $\alpha \in [0, 1]$, weights the importance of the community in the strategy decision for each household. Its value is fixed in time.
- The homophily parameter, $h \in [0, 1]$ represents the desired proportion of neighbours matching the same crop planting choices. The homophily parameter is also fixed in time.
- At each time step all households update their state σ_i to maximize their payoff (last bullet point). The total number of time steps or iterations is given by *T*.
- The satisfaction function $s_i \in [0, k_i]$, where k_i is the degree of node *i*, depends on the distance Δ_i, which measures how close are the links of a node from their optimal configuration. In other words, it retrieves the distance with respect to the number of connected households with same crop, according to h.

(1) $\Delta_i = |h - \frac{1}{k_i} \sum_j \delta_{\sigma_i \sigma_j} a_{ij}|$

(2) $s_i = k_i e^{-\Delta i}$

- The payoff function $\Pi_i \in [0, \max k_i]$ depends on the individual and the community satisfactions, weighted by the individual other-regarding preferences parameter.

Therefore the payoff is not a purely economic measurement, but it depends on both economic and personal behaviour.

(3) $\Pi_i = (1 - \alpha)s_i + \frac{\alpha}{N}\,\Sigma\, s_i$

The homophily parameter can capture both coordination (h ≈ 1) and anti-coordination dynamics (h ≈ 0) and the situations in between. The last two points indicate that individual satisfaction is subjective to each household and driven by own level of homophily: own satisfaction is assessed in comparative terms. Other households are considered in terms of their state (i.e. the planted crop) and we assume full knowledge of nodes state within the network.

Payoff combines individual and community satisfaction; here the other-regarding preferences parameter is key: the higher the more important will be the satisfaction of others. This formalization allows the consideration of two scales of concern (individual and communal) in the objective function driving household behaviour.

We consider cooperation as driven by the importance assigned to the community in terms of neighbours' satisfaction. In this framework, high other-regarding preferences (α ≈ 1) means to adapt crop selection so that neighbours' satisfaction can maximize individual payoff in addition to individual satisfaction. Low other-regarding preferences (α ≈ 0) means to not consider neighbours' satisfaction. Regardless of this parameter all households maximize their own payoff and thus are modelled as self-interested individuals.

In the following section, we describe the model behaviour by means of numerical simulations on artificial networks of different kinds. Then, in Results, we apply the model to the data of a village in Southern Malawi and summarize the main findings.

2.3 Model behaviour

The game theory model has three control parameters, namely the other-regarding preferences parameter α, the homophily parameter h, and the number of possible node states S, which represent the main crop types. The model can be implemented on different network topologies (Latora, Nicosia and Russo 2018). Here we compare three networks, namely Regular Lattices (RL), Random Networks (RN) and Scale Free Networks (SF), with the same number N = 100 of nodes and the same average degree <k> = 4. Regular Lattices of <k> = 4 correspond to a uniform distribution of the nodes in the plane, where each node is connected to its two nearest neighbours in each dimension. In order to have <k> = 4 for all the nodes, we considered periodical boundaries. Random Networks (Erdos and Rényi 1960) of N nodes and <k> = K are achieved by fixing the link probability to K/(N-1). Their degree distribution can be well approximated with a Poisson probability distribution. Scale Free Networks (Barabási and Albert 1999) are characterized by a power law decay in the degree distribution, allowing the existence of hubs, or nodes with a high degree.

Simulations have been performed for $\alpha \in \{0, 0.5, 1\}$, $h \in \{0, 0.5, 1\}$, and $S \in \{2, 3, 4, 5\}$, and the results have been averaged over ensembles of 100 different network realizations. In each simulation we have run the game for T = 20 iterations under a best response update rule, which assumes that each of the nodes tests all the possible states and selects the one with the highest payoff. The value of T = 20 is enough to guarantee the convergence of the system to the equilibrium state. The combination of the best response update mechanism and the small size of network explains why most of the information of the equilibrium solution is provided for small values of T (e.g. T = 5).

The asymptotic values of payoff and dominating state fraction are shown in Fig. 2 and Fig. 3. The first is the value of payoff when the system approaches equilibrium, the latter represents the proportion of households within the village matching the same crop planting choices. Both figures show the average values of output as a function of other-regarding preferences and homophily for different topologies and values of S. The columns correspond to the topology, RL, RN and SF, while the rows correspond to the total number of states. In each subplot the colour in the white-blue scale represents the value of the payoff for the specific selection of α and h.

From the simulations we can infer the most relevant features of the model:

- The relation between S (number of states/crops) and <k> (average degree of the network) determines the strategy with the highest payoff. For low S/<k>, conformation is more favourable than differentiation. The opposite is true for higher values of S/<k>.
- The system is polarized between consensus (high dominating state fraction (df)), for h = 1, and dissension (low df), for h = 0. The intermediate situations imply lower payoffs. This indicator suggests the existence of a phase transition between these two regimes.
- Cooperation is especially relevant when the community converges on crop planting choices: it is a necessary ingredient for the success of households that conform. The opposite is not true. Differentiation can survive without cooperation.
- The dynamics are stable except for the combination of h = 0.5 and $\alpha \in \{0.5, 1\}$. We expand on this finding when studying the empirical case study. The higher S, the lower the fluctuations. The tendency towards stability depends on the topology. RL achieve it faster than SF, and these are faster than RN (See Online Resource 1: Fig. 6 and Fig. 7. Here we plot the absolute value of the discrete derivative at T = 20, as a mechanism for evaluating if the result corresponds to an equilibrium situation).

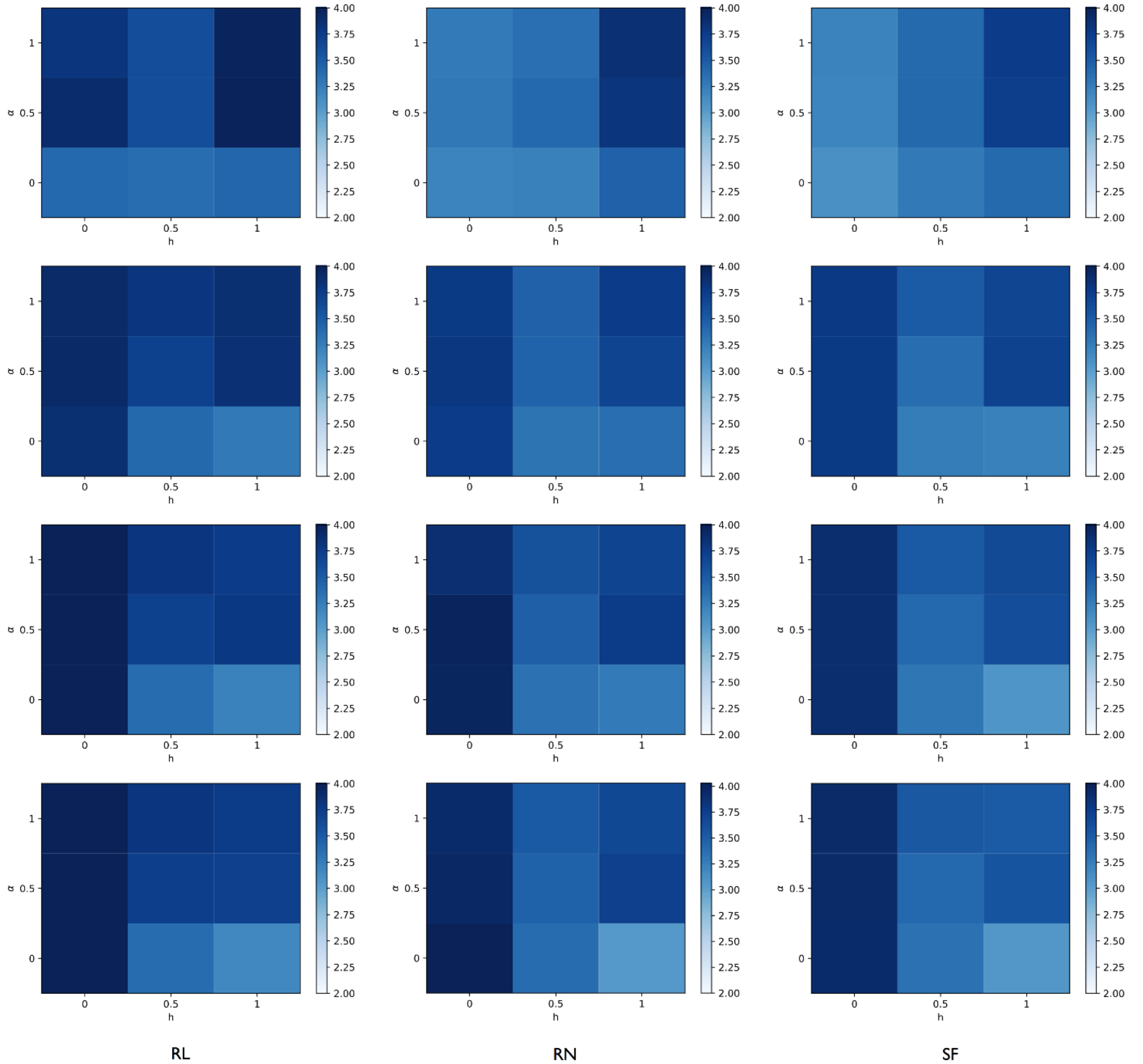

Fig. 2 Payoff when the system approaches equilibrium (asymptotic payoff) for different values of other-regarding preferences and homophily in different network topologies. Number of nodes N = 100, iterations T = 20, average degree <k> = 4. Each row of figures corresponds to the simulations for a number of node states S = {2, 3, 4, 5}. The columns refer to the type of network: Regular Lattice (RL), Random Network (RN) and Scale Free Network (SF). Each subfigure represents a combination of type of network and total number of node states. The squares in the subfigures describe the payoff in a scale from 2 (lighter) to 4 (darker) for different combinations of other-regarding preferences and homophily.

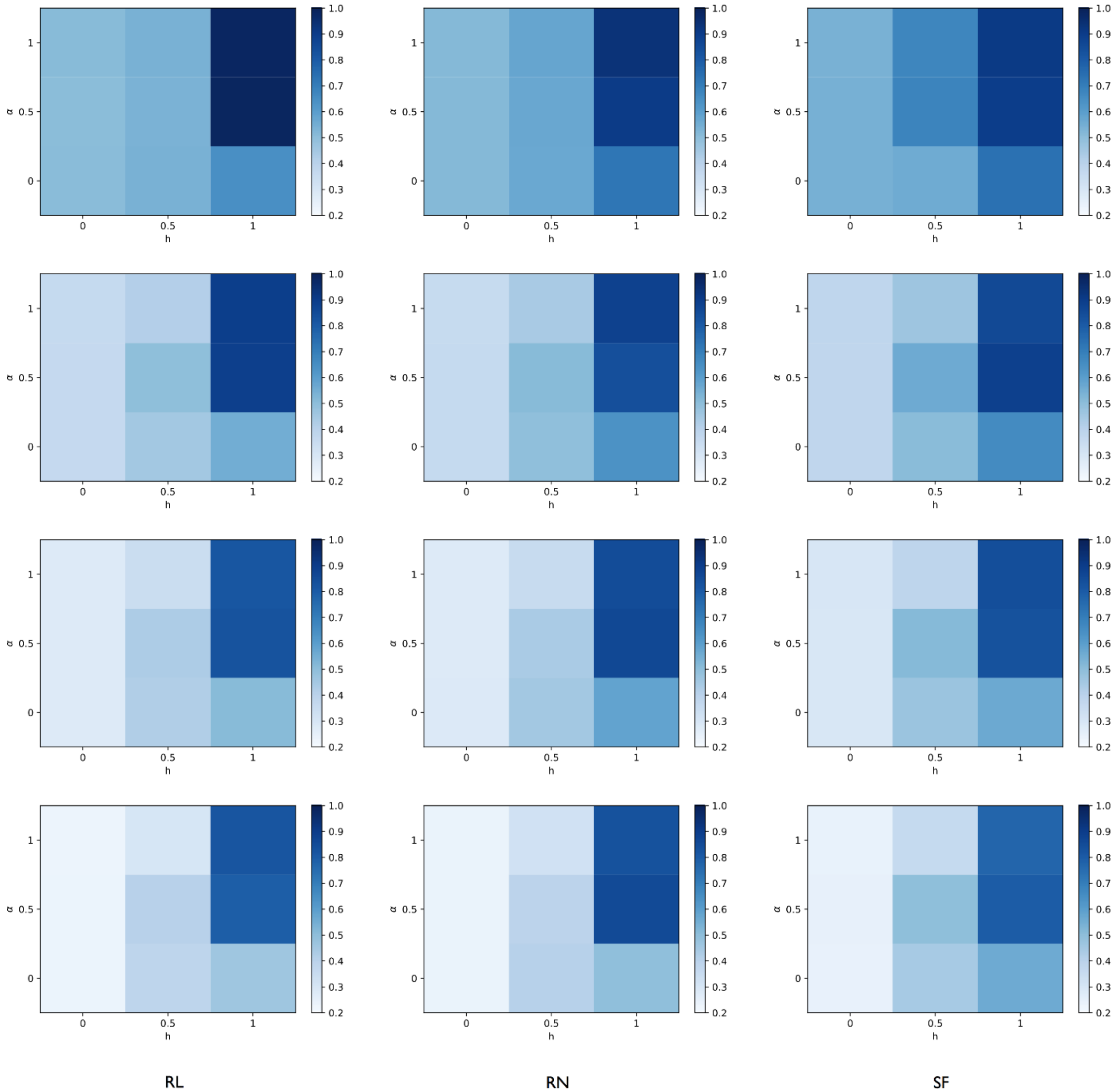

Fig. 3 Proportion of households converging to the same crop selection (dominating state fraction) for different values of other-regarding preferences and homophily in different network topologies. Number of nodes N = 100, iterations T = 20, average degree <k> = 4. Each row of figures corresponds to the simulations for a number of node states S = {2, 3, 4, 5}. The columns refer to the type of Network: Regular Lattice (RL), Random Network (RN) and Scale Free Network (SF). Each subfigure represents a combination of type of network and total number of node states. The squares in the subfigures describe the dominating state fraction in a scale from 0.2 (lighter) to 1 (darker) for different combinations of other-regarding preferences and homophily.

3. Results

For the case under study, a small village in Southern Malawi, we have S = 4 main crop types, and precise information on the type of crop adopted by each one of the 46 households in the village. The total number of crops is 8, but our model only takes into consideration the crop with the maximum harvesting quantity for each household. Even after this simplification, the use of the different crops is quite heterogeneous, with adoption frequencies equal to (35, 9, 1, 1). These values account for the number of households that have selected each of the crops as their preferred option and correspond to 76% of the households adopting the same crop, making the dominating state fraction (df) equal to 0.76. (See Online Resource 1, Fig. 8).

Our purpose here is to map the village in the bi-dimensional space described by the behavioural compass (Fig. 1), by matching the model outcomes with the crop statistics observed in the data. At the same time, this study shows the combination of other-regarding preferences and homophily parameters valid for the description of real scenarios.
In order to make use of our game theory model in a social network setting, we need to infer the topology of the real network of interactions among households, which defines the neighbours considered when measuring own satisfaction. This data was not collected and is typically difficult to access.
A reasonable assumption is to model the social network in the village as a small world. Small world networks (Watts and Strogatz 1998) are characterized by short average path lengths (i.e. shortest path between all pairs of households) and high clustering (i.e. the ratio of household connections that are connected among themselves). Such assumption is also supported by evidence from the literature (e.g. Spielman et al. 2011, Ligon and Schechter 2012).

The small world topology can be achieved with the Watts-Strogatz mechanism based on the random rewiring of regular ring lattices (Watts and Strogatz 1998). Based on Dobbie et al. (2018), who modelled the same village setting with a coupled agent-based and network approach, we simulated the households as a small-world network with N = 46 average degree $\langle k \rangle = 9$ and rewiring probability p = 0.25. For this topology we run the game trying to determine the value of h that corresponds to df = 0.76. In order to do so, we discretize the [0, 1] interval in 20 parts and obtain the value of the payoff and df of an ensemble of 100 networks in each of them (See Fig. 4).

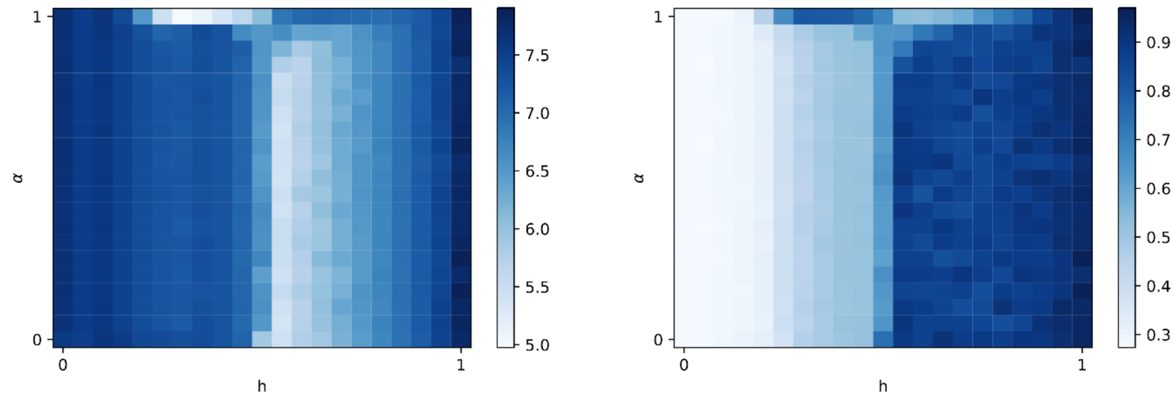

Fig. 4 Case analysis: a Southern Malawi village. Simulations for an ensemble of 100 small world networks of N = 46 nodes, average degree <k> = 9, and rewiring probability p = 0.25, for different values of homophily (h) and with number of node states S = 4. Payoff is displayed on the left side and dominating state fraction on the right side. Both display three different regimes of the system, with higher values in darker shades.

In the numerical simulations we find three different regimes of the system:

1. The first one, for h < 0.5, is characterized by a high payoff. The dominating state fraction (df) increases with h, which enables a large average payoff, because households tend to experience in their neighbours the diversity of crops desired. In other words, the households succeed in adapting to a relatively high level of diversity, and achieve an overall high payoff for the village.
2. In the second regime, h > 0.5, the system is driven to consensus (df > 0.8), which is rewarded for high values of h, but not for average ones. For h < 1 households aim at a small amount of diversity among crops, but the system does not provide it. Thus a higher payoff is granted to the households that conform. Differently from the first region, households are driven to consensus for all the values of h, which is detrimental in terms of payoff.
3. The last regime is found in the area between the previous two. It is constrained to the values close to h = 0.5 and α = 1. In the frontier with the second region, h > 0.5, we can see how cooperation allows to adapt the df to the value of h. The opposite behaviour is achieved for h < 0.5: the fluctuations break the successful dynamics of the best response mechanism and lead to a consensus state. Therefore, within the third region, cooperation is beneficial when the system is characterized by h > 0.5, and detrimental for h < 0.5.

It is important to notice that, in the first two regions, the payoff is largely determined by the homophily parameter (h) and the other-regarding preferences parameter (α) is almost irrelevant. Both differentiation and conformation can be successful strategies although they imply very different outcomes at the system level: dissension in the first case and consensus (on which crop to plant) in the latter.

However, the third region, as we show in the next paragraphs, is the one where our case study is located: maize is the widely preferred staple food and most of the residents wouldn’t consider a meal without maize as satisfactory (Dorward and Kydd 2004). The main property of the third region is that it switches the behaviour of the two other regions at their margins. With high other-regarding preferences, when everybody’s satisfaction is considered in the individual payoff, conformation can lead to higher payoffs.

In order to fit our model to the village dataset, we considered values in an interval of 0.01 with respect the observed df. However, these results suggest the existence of a continuous function of α and h fulfilling the desired condition, df = 0.76 ± 0.01, which may be achieved by increasing the resolution in the simulations. To this end we have further inspected the system around the third region, zooming into values of h constrained to the [0.45, 0.55] interval (Online Resource 1, Fig. 9), and separately, to values of α constrained to the [0.9, 1] interval (Online Resource 1, Fig. 10).

The first zoom sheds light on the fact that cooperation with intermediate values of h prevents the system from achieving an equilibrium situation. However, the highest fluctuations of df have an higher bound of 0.12, which indicates an overall predictable behaviour. The second zoom explains the success of cooperation for h > 0.5 and its redundancy for h < 0.5. The simulation shows that the fluctuations are exclusive of the h < 0.55 region, and prevent the system from achieving a higher payoff. Thus we cannot associate this outcome to a stationary state of the system.

Finally, we identify the values of α and h that correspond to the dataset provided by our case study (Online Resource 1, Table 2). We can distinguish two sets of points. A first one of h < 0.5 and α = 1, and a second one with h > 0.5. As we anticipated, the first set lies in a high fluctuations region, we therefore focus on the second one, for which we fit a curve that provides the part of the phase space that corresponds to our dataset (Fig. 5). Fig. 5 reinforces the insight provided by the analysis of the generic model in Section 3.1: conformation is a winning strategy when cooperation is in place. In particular, the last two points display above average payoffs. In the next section we elaborate on what are the implications of these dynamics in terms of food security.

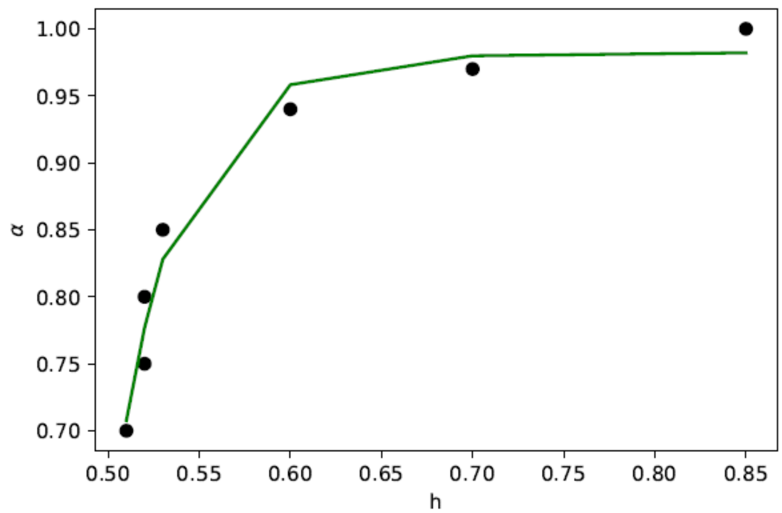

Fig. 5 Curve fitting the combinations of homophily (h) and other-regarding preferences (α) with highest payoff. The dots show the points with homophily h > 0.5 in Table 2 (Online Resource 1), which are the combinations of h and α for which the value of dominating fraction in the numerical simulations matches the one of the village. The relation between the parameters of the behavioural compass, which describe the village, is captured by the non-linear function $\alpha = a\,h^{-15} + b$ with $a = -1.12795\ 10^{-5}$ and $b = 9.8225\ 10^{-1}$

4. Discussion

This article has presented the behavioural compass—a way of framing human decisions considering the predisposition of human beings to compete/cooperate with and imitate/differ from own peers—and applied it to the case of community food security in a rural region of the Global South. Although we argue that this representation of human behaviour could be applied to a heterogeneous set of social phenomena, including off-farm livelihood strategies, this is outside the scope of the current article.

The Sustainable Development Goals (SDGs) adopted by the United Nations have set a clear target to end food insecurity by 2030. The aim of Goal 2 is to “end hunger, achieve food security and adequate nutrition for all, and promote sustainable agriculture.” How agri-food systems can self-organize to promote practices capable of meeting this goal is still an open question. A review by Rausser et al. (2015) describes two main global paradigms: the Industrial food and agricultural industry (IFA) and the naturalization food and agricultural paradigm (NFA). IFA relates to industrial food production and large-scale food distribution system; NFA captures a multi-faceted movement concerned with key principles such as: local, small and organic; slow food (Petrini 2003); agroecology (Gliessman 2009); food sovereignty (Patel 2009) and diversified farming systems (Kremen and Miles 2012).

It is reasonable to think that that agri-food systems can be mapped within a continuum between these two paradigms and dynamically move in one direction or the other according to social and ecological conditions. For example, a country of the Global South like Malawi has been witnessing a shift towards IFA under the liberalisation reforms that happened since the eighties (Dorward and Kydd 2004). At the same time NFA is gaining momentum in the cities of the Global North, where the masses have been relying on the IFA paradigm, almost since the industrial revolution (Ilieva 2016).

In this study we adopted a village-centric perspective and a system approach, whereby the system performance is stemming from the behaviour of and interactions among the individual components, to explore how household behaviour can affect food security at the community level. We implicitly considered that self-sufficiency in food production is a positive feature for a rural agri-food system of the Global South, but here we discuss its consequences.

Because satisfaction, and thus payoff, is not measured in terms of nutritional requirements we can only suggest how human behaviour is expected to influence food security. Indeed, our model is primarily concerned with behavioural dynamics in crop adoption and the level of dissension/consensus within the community. To draw conclusions on the nutritional level of community food security, we would have to couple this behavioural model with agricultural and environmental modules (see Balbi et al. 2015) and a module of exchanges, including market interactions and bartering dynamics, possibly considering food imports and exports. In the work presented here we assume that all the households have the same nutritional requirements, and that the production costs and economic profit are equal for all crop types. We also don't consider any difference in the crops that are consumed by the producers and the ones that are sold in market. Accessing food via production or via market doesn't affect the benefits and food price is exactly the production cost, thus the community is assumed to operate through direct food exchanges.

Although past studies have emphasized the role of cooperation in self-organized systems (see Perc et al. 2017 for a review), our game theory model suggests that homophily—the continuum between conformation and differentiation—can play a relevant role. Both conformation and differentiation can be successful strategies leading to high payoffs at the individual level, but according to which prevails, they drive the system to very different community outcomes. In the first case, we have a community converging on crop planting choices, in the second case the community maintains crop diversity.

Both cases can happen regardless of the importance given to others satisfaction, which is what drives cooperation in our model. This can have significant consequences in terms of food security at the village level. The first case is a specialization case that could succeed only if the village is connected to the outside via food exchange mechanisms (e.g. regional food markets) through which households can sell their own produce and buy the lacking nutrients. The alternative is a community that can perhaps self-sufficiently meet its own caloric needs, but not a healthy diet diversity. The second case is a diversification case that can succeed under a self-sufficiency scenario, but requires internal exchanges to happen (via local market or bartering) within the village to meet the necessary diet diversity at the household level.

However, the case study we analysed in this article, using empirical data from a rural village in Southern Malawi, has provided more insights about the role of cooperation. Our analysis suggests that the village is located in a very particular region of the parameters space where the influence of other-regarding preferences is relatively high for any point in the curve presented in Figure 5. This curve acts as the boundary between the regions representing the two cases mentioned above. Thus cooperation has a key role to play: the higher other-regarding preferences the more the system is driven to consensus, and the analysis of expected payoffs suggests that the village is better off with consensus. Partial dissension can survive for other-regarding preferences below 0.9. It thus seems that sacrificing some degree of cooperation in favour of more crop diversity would reduce the individual expected payoff, although it would make sense from a nutritional diversity perspective at the community level. Indeed, the current village situation is confirming these insights: in this part of Malawi food exchanges are largely market-driven with regional markets playing an important role and maize is by far the socially preferred crop (Schreckenberg et al. 2016). Moreover, the results reinforce the idea of close to perfect knowledge among households at the village scale, and the convenience of considering others satisfaction in own payoff, thus being more cooperative.

One additional limitation of our work is the assumption about the real topology of the village network. Although we expect an error of approximation of the actual social network, our assumption is based on previous studies and the sensitivity analysis in Section 2.3 explains the similarity of model behaviour when the topology is altered. Accordingly, we expect the relation between the other-regarding preferences and the homophily parameters to be robust against changes in the topology. For what concerns village-level results, we expect them to hold for small communities (e.g. 30 to 100 households corresponding to 100-500 individuals) with a relatively high degree of mutual knowledge among community members and parcelled access to the resource—in this case farming land.

Further analysis will explore the explanatory power of the behavioural compass at multiple spatial scales. We argue that the behavioural compass could be extended on a third axis, thus representing a three dimensional space, to capture multiple levels of governance (Lebel et al. 2006) and their institutions (from the micro- to macro-scale), in line with the thinking of Waring et al. (2015).

5. Conclusions

The main finding of our simulations suggests that individual and community success is more strongly related to personal behaviour than to economic behaviour. In other words, how individuals relate to social norms has greater effect than how much they care about the success of their neighbours (i.e. our working definition of cooperation). While we expected the latter to be the main driving force in determining community success, we found that cooperation is only necessary for community success when the community converges on crop planting choices. On the contrary, differentiation, the affirmation of the individual unique identity, can succeed with or without cooperation.

Under a food security perspective, when there is a diversity of options about crop adoption, differentiation is likely to deliver more positive outcomes. Only when the options are few, then conformation is a winning strategy. In a situation such as a rural region of the Global South—in this article we used the example of a village in Southern Malawi—this translates into clear policy implications about the role of food sovereignty, and in particular food knowledge sharing. Food security, among other things, depends on a variety of nutrients for a healthy and balanced diet, thus enabling biological diversity in agriculture can be beneficial.

Instead, it seems that the policy reforms of the past have pushed countries like Malawi, similarly to other rural African regions, to specialize their agricultural production towards one or two socially preferred crops, via crop-specific subsidies and other incentives. This made sense under a scenario of market liberalisation that was going to deliver efficient redistribution of food commodities among different regions (for food security purposes), thus allowing beyond-system food transactions. Evidence from the ground suggests that this paradigm has only partially delivered its promises (see Dorward and Kydd 2004) and that stimulating more diverse crop adoption at the household level is a reasonable strategy to improve community food security.

We argue that this process is not likely to happen endogenously, because, in the current setting, households regard conformation as a safer strategy, due to the dominant social norms on crops.

Acknowledgments

This research is supported by the Basque Government through the BERC 2018-2021 program and by the Ikertzaile Doktoreentzako Hobekuntzarako doktoretza-ondoko Programa, and by Spanish Ministry of Economy and Competitiveness MINECO through BC3 María de Maeztu excellence accreditation MDM-2017-0714 and by the Leverhulme TrustResearch Fellowship "CREATE: the network components of creativity and success. This work was also inspired and partially funded by the ASSETS (Attaining Sustainable Services from Ecosystems) project (NERC/ESPA NE-J002267-1). The authors wish to thank the advice and support of Marije Schaafsma (University of Southampton), who provided the dataset analysed, Kate Schreckenberg (King's College London), who led the work on the participatory rural appraisals within the ASSETS project, Samantha Dobbie for the extensive work on sustainable livelihoods achieved during her doctoral research at the University of Southampton, and Ortzi Akizu-Gardoki (University of the Basque Country) for the design of Figure 1.

References

Anderman TL, Remans R, Wood SA, DeRosa V, DeFries RS (2014) Synergies and tradeoffs between cash crop production and food security: a case study in rural Ghana. Food Security 6(4):541–554. doi: 10.1007/s12571-014-0360-6

Axelrod R., Hamilton WD (1981) The evolution of cooperation. Science 211(4489):1390–1396. doi: 10.1126/science.7466396

Balbi S, del Prado A, Gallejones P, Geevan CP, Pardo G, Pérez-Miñana E, Manrique R, Hernandez-Santiago C, Villa F (2015) Modeling trade-offs among ecosystem services in agricultural production systems. Environ Modell Softw 72:314-326. doi: 10.1016/j.envsoft.2014.12.017

Barabási AL, Albert R (1999) Emergence of scaling in random networks. Science 286(5439): 509-512. doi: 10.1126/science.286.5439.509

Burchi F, De Muro P (2016) From food availability to nutritional capabilities: Advancing food security analysis. Food Policy 60:10–19. Doi: 10.1016/j.foodpol.2015.03.008

Chambers R, Conway G (1991) Sustainable rural livelihoods: Practical concepts for the 21st century. IDS Discussion Paper 296. http://opendocs.ids.ac.uk/opendocs/handle/123456789/775 Accessed 09 March 2020.

Chappell MJ, LaValle LA (2011) Food security and biodiversity: can we have both? An agroecological analysis. Agric Hum Values 28(1):3-26. doi: 10.1007/s10460-009-9251-4

Chinsinga B, Chasukwa M (2012) Youth, agriculture and land grabs in Malawi. IDS Bulletin 43(6): 67–77. doi: 10.1111/j.1759-5436.2012.00380.x

Connolly-Boutin L, Smit B (2016) Climate change, food security, and livelihoods in Sub-Saharan Africa. Reg Environ Change 16(2):385–399. doi: 10.1007/s10113-015-0761-x

Deutsch M (1949) An experimental study of the effects of cooperation and competition upon group process. Human Relations 2(3):199–231. doi:10.1177/001872674900200301

Devereux S (2016) Social protection for enhanced food security in Sub-Saharan Africa. Food Policy 60: 52–62. doi: 10.1016/j.foodpol.2015.03.009

Dobbie S, Schreckenberg K, Dyke J, Schaafsma M, Balbi S (2018). Agent-based modelling to assess community food security and sustainable livelihoods. Journal of Artificial Societies and Social Simulation 21(1):1-23. doi: 10.18564/jasss.3639

Dobbie S, Balbi S (2017) Design of an empirical agent-based model to explore rural household food security within a developing country context. In: Jager W, Verbrugge R, Flache A, de Roo G, Hoogduin L, Hemelrijk (eds.), Advances in Social Simulation 2015, Cham: Springer, pp 81–94. doi: 10.1007/978-3-319-47253-9_7

Dorward A, Kydd J (2004) The Malawi 2002 food crisis: the rural development challenge. The Journal of Modern African Studies 42(03):343–361. doi:10.1017/S0022278X04000229

Erdos P, Rényi A (1960) On the evolution of random graphs. Publ Math Inst Hung Acad Sci 5(1):17-60.

Fehr E, Fischbacher U (2002) Why social preferences matter–the impact of non-selfish motives on competition, cooperation and incentives. The economic journal 112(478):C1–C33. doi: 10.1111/1468-0297.00027

Gliessman, S. (2009) Editorial: A Framework for the Conversion to Food System Sustainability. Journal of Sustainable Agriculture 33(1):1-2. doi: 10.1080/10440040802587249

Gondwe GE (2014) 2014 Millennium Development Goal Report for Malawi. Ministry of Finance, Economic Planning and Development, Lilongwe, Malawi. http://www.undp.org/content/dam/malawi/docs/general/Malawi_MDG_Report_2014.pdf Accessed 09 March 2020.

Headey, D, Ecker O (2013) Rethinking the measurement of food security: From first principles to best practice. Food Security 5(3):327–343. doi: 10.1007/s12571-013-0253-0

Ilieva, RT (2016) Urban food planning: seeds of transition in the global north. Routledge.

Kahneman, D (2011) Thinking, fast and slow. Macmillan.

Kremen C, Miles A (2012) Ecosystem services in biologically diversified versus conventional farming systems: benefits, externalities, and trade-offs. Ecology and Society 17(4):40. doi: 10.5751/ES-05035-170440

Latora V, Nicosia V, Russo G (2018) Complex Networks: Principles, Methods and Applications. Cambridge University Press.

Lebel L, Anderies JM, Campbell B, Folke C, Hatfield-Dodds V, Hughes TP, Wilson J (2006) Governance and the capacity to manage resilience in regional social-ecological systems. Ecology and Society 11(1):19.

Lester JC (1994) The evolution of the political compass (and why libertarianism is not right-wing). Journal of Social and Evolutionary Systems 17(3):231–241.

Ligon E, Schechter L (2012) Motives for sharing in social networks. J Dev Econ 99(1):13–26. doi: 10.1016/j.jdeveco.2011.12.002

Maddox WS, Lilie SA (1984). Beyond liberal and conservative: Reassessing the political spectrum. Cato Institute.

NSO (2012) Malawi Integrated Household Survey 2010-11 (IHS3). National Statistical Office, Lilongwe. http://microdata.worldbank.org/index.php/catalog/1003 Accessed 09 March 2020.

Orr A, Mwale B, Saiti-Chitsonga D (2009) Exploring seasonal poverty traps: The 'Six-Week Window' in Southern Malawi. The J Dev Stud 45(2):227–255. doi: 10.1080/00220380802265330

Ostrom E (2009) A general framework for analyzing sustainability of social-ecological systems. Science 325(5939):419–422. doi: 10.1126/science.1172133

Patel R (2009) Food sovereignty. The Journal of Peasant Studies 36(3):663–706. doi: 10.1080/03066150903143079

Perc M, Jordan JJ, Rand DG, Wang Z, Boccaletti S, Szolnoki, A. (2017). Statistical physics of human cooperation. Physics Reports, 687, 1-51. doi: 10.1016/j.physrep.2017.05.004

Petrini C (2003) Slow food: The case for taste. Columbia University Press.

Rausser G, Zilberman D, Kahn G (2015) An alternative paradigm for food production, distribution, and consumption: A noneconomist's perspective. Annual Review of Resource Economics 7(1):309–331. doi: 10.1146/annurev-resource-100913-012549

Sahley C, Groelsema B, Marchione T, Nelson D (2005) The governance dimensions of food security in Malawi. USAID Bureau of Democracy, Conflict, and Humanitarian Assistance, Washington, DC. https://sarpn.org/documents/d0001649/P1998-USAID_Malawi_Sept2005.pdf Accessed 09 March 2020

Schmidhuber J, Tubiello FN (2007) Global food security under climate change. PNAS 104(50):19703–19708. doi: 10.1073/pnas.0701976104

Schreckenberg K, Torres-Vitolas CA, Willcock S, Shackleton C, Harvey CA, Kafumbata D (2016) Participatory Data Collection for Ecosystem Services Research: A Practitioner's Manual. ESPA Working Paper Series No 003/June 2016. ISSN 2058-9875 http://www.espa.ac.uk/files/espa/PRA-Manual.pdf Accessed 09 March 2020

Spielman DJ, Davis K, Negash M, Ayele G (2011) Rural innovation systems and networks: Findings from a study of Ethiopian smallholders. Agric Hum Values 28(2):195–212. doi: 10.1007/s10460-010-9273-y

United Nations (2015a) Transforming our world: The 2030 agenda for sustainable development. Resolution adopted by the General Assembly.

United Nations (2015b) World urbanisation prospects: The 2014 revision. The Population Division of the Department of Economic and Social affairs of the United Nations.

Waring TM, Kline MA, Brooks JS, Goff SH, Gowdy J, Janssen MA, Smaldino PE, Jacquet J (2015) A multilevel evolutionary framework for sustainability analysis. Ecology and Society 20(2):34. doi: 10.5751/ES-07634-200234

Watts DJ, Strogatz SH 1998. Collective dynamics of 'small-world' networks. Nature 393(6684): 440–442

Witkin HA, Price-williams D, Bertini M, Christiansen B, Oltman PK, Ramirez M, Meel JV (1974) Social conformity and psychological differentiation. International Journal of Psychology 9(1):11–29.