A Framework for the Exploration of Critical Factors on Promoting Two-Season Cultivation in India

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To promote a new mode of production and a changed lifestyle in a relatively closed, underdeveloped community, critical interventions should be explored, and, as appropriate, implemented. Different scenarios are identified and explored so that decision support can be provided to social entrepreneurs (SEs). Here, agent-based modeling (ABM) is used to simulate villagers' acceptance of second-season cultivation, growing two crops a year instead of one. We explore the possibility of second-season cultivation to improve the villagers' social-economic status in both the short term and the long term. The proposed method of capturing and making use of critical factors in influencing individuals' behavior in a community can be used in other projects. Our focus in here is on the method, rather than the specific results.
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1 Background

1.1 Frame of Reference. It is challenging to change people's mode of making a living and lifestyle when a new technology is available, especially in relatively closed and underdeveloped areas [1,2]. Modeling methods and simulations are used to predict people's acceptance and adoption of a new lifestyle or technology, but often the verification of the simulations and the validation of the utility of the method are missing [3,4]. Because of unavoidable errors and flaws in modeling [5] and due to the complexity of the model environment, methods such as sensitivity analysis [6,7] and Monte Carlo analysis [8] are often used to manage uncertainties and provide decision support in a changing environment. However, for the design of sociotechnical systems, where the initial data are lacking or difficult to verify and quantify [9], and when the future is uncertain, we need a method to explore the variability of the model results and identify sensitive factors that contribute to variabilities [6].

From the literature on simulating social behaviors and providing decision support for policy-making, agent-based modeling (ABM) is a practical tool [10]. There are many examples of the use of ABM to observe patterns in collective behavior, identify critical factors, and intervene in the system by changing critical factors, including the exploration of the extent of influence, or radius of influence, among neighbors with respect to promotion actions [11], the identification of critical factors that contribute to population dynamics [10], the estimation of the effects of policy interventions on the investment in new equipment [12], and decision support for managing the potential labor reproduction [13]. In Table 1, we list some representative publications on capturing social behavior and leveraging critical factors to serve a promotion goal. However, there is less literature on decision support based on planning for various scenarios. Therefore, here, we provide scenario-planning-based decision support to social entrepreneurs, SEs, with respect to reaching social-economic goals in various situations. We use a test problem of promoting second-season cultivation, that is, growing a second crop each year in an underdeveloped, rural Indian village.

1.2 A Test Problem. Our objective is to give decision support to SEs promoting second-season cultivation in Kudagaon, a relatively isolated and underdeveloped village in Odisha, India. Kudagaon is a village on an island surrounded by a river (Fig. 1). There are 85 households in the village and each household has some farmland. There is a rainy season (or monsoon season) and a dry season. Most households do one-season cultivation, growing rice or vegetables in the rainy season using the water from the river. In the dry season, the water level of the river drops significantly, so the majority of the families cannot farm because of the scarcity of water. Therefore, two-season cultivation is not possible; hence, the villagers cannot increase their household savings by two-season cultivation. It has been determined that Kudagaon has sufficient underground water for farming in the dry season, but villagers need to purchase or rent equipment to pump the underground water and transport it to their farmland. Since most families do not have adequate savings, they cannot afford the equipment. This is a dilemma.

When a household (family) grows crops only once a year, during the dry season, the main laborer(s) of the household migrate so that they can obtain daily wages. These daily wages are their families' only source of income in the dry season. We call this "migration income." Migration income is usually less than the income which could be garnered from second-season cultivation, assuming sufficient water. In addition, the wellbeing of families with migration worker(s) (these are "migration families") regarding household stability and social status is worse than that of the families who do two-season cultivation (these are "cultivation families"). However, during the rainy season, families who do one-season cultivation when their farmlands are away from the river may still consider growing crops in the dry season based on the specific climate and the market situation each year. They can lease equipment and water pumps to get underground water for second-season

Table 1 Some representative applications of ABM for new technology acceptance and policy impact

Author and year	Problem description	Method	Results	Contribution
Opiyo, 2019 [11]	Study neighborhood influence and social pressures on temporal diffusion of solar home systems (SHS)	Agent-based modeling with survey data	Visibility of newly installed SHS and increasing influence radius leads to growth in SHS installations	The survey method is helpful to acquire relatively quantifiable data for a social problem
Qiu, 2018 [10]	Simulate urban land development and population dynamics	An agent-based and spatial genetic algorithm framework (PDULD)	Government policies dominate the process of land development	Community cohesion theory is introduced into the model; historic data are used to verify the results
Al Irsyad et al., 2019 [12]	Estimate the effects of four solar energy policy interventions on photovoltaic (PV) investments, government expenditure, economic output, etc.	Uses hybrid energy -agent-based modeling	Results call for PV donor gift policy, the improvement of production efficiency, after-sales services and rural financing institutions	Integrate input–output analysis, environmental factors and socioeconomic characteristics of households in Indonesia
Rossoshanskaya, 2019 [13]	Simulate labor potential reproduction; among the scenario forecasts, provide decision support on management actions	Agent-based modeling with multi-agents and multi-scenarios	The integrated agent-based model of labor potential reproduction at the municipal level	The model is filled with sociological and statistical data and has a user-friendly interface

cultivation, but the cost is high, and the risk is high. However, if they anticipate that they may gain more profit through second-season cultivation than doing migration work, they may stay and grow second-season crops instead of migrating. Currently, the probability of a household which does one-season cultivation to switch to two-season cultivation is as low as 5%. This number has been provided by our colleagues, the SEs at SunMoksha, based on historic data and from interviews of the villagers.

The role of a SE in this project is to help villagers in Kudagaon improve their social and economic status by promoting second-

Fig. 1 The satellite map of Kudagaon

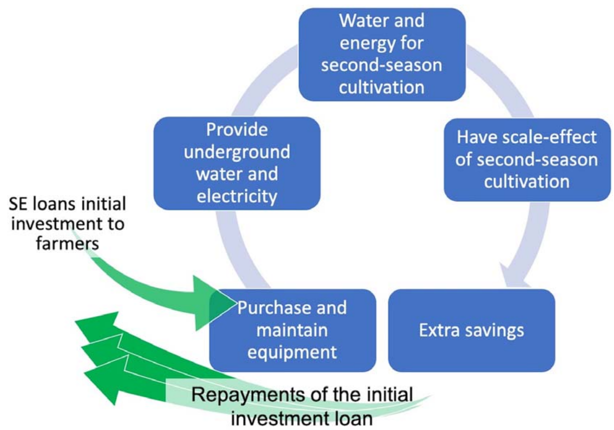

Fig. 2 The SE's plan for facilitating second-season cultivation

season cultivation. The SE plans to provide farmers the initial investment as loans to construct public infrastructure so that electrical power can be generated and underground water may be obtained, and transporting the water and electricity to make farming possible in the dry season. The underground water and electricity are provided to farmers as utilities using affordable, tiered pricing. After the farmers profit from the second-season cultivation and have savings, they repay the loans within several years. In Fig. 2, we illustrate how the initial investment from the SE helps to make second-season cultivation feasible.

The acceptance of second-season cultivation is crucial for the success of this project. Hence, in addition to loans and technical support, it is important to promote second-season cultivation among farmers. The benefits from second-season cultivation include improving a household's economic and social status with a higher and more stable income and keeping the household together. However, not all villagers realize these benefits, and there is a considerable reluctance to change one's mode of production, lifestyle, and source of income.

Based on the dilemma and the difficulties that the SE encounters, we summarize the SE's possible actions and targets in Table 2. Each target either improves the villagers' social status, or improves their economic status, or both. We hypothesize that by increasing the two-season cultivation households, there can be a scale effect due to stable market demand and lowering the unit cost of storage and transportation; thus, villagers' income can be increased and their economic status can be enhanced. An SE's job is to boost villagers' economic and social status in both the short term and long term. In the short term, the SE wants to improve the two-season cultivation rate from β_1 to β_2,

Table 2 The SE's target based on the current situation

Current problem	Reason or dilemma	SE's action	Target	Category
Only β_1 of the households anticipate a better profit of second-season cultivation so they grow twice a year $\beta_1 \approx 5\%$	Farmers cannot afford the equipment to acquire underground water for farming in the dry season	Having promotion activities[a]; providing underground water	Raising the second-season cultivation rate from β_1 to β_2 in the promotion year	Short-term economic status—increase profit level
			Maintaining the second-season cultivation rate of β_3 after two years following the promotion year	Long-term economic status–stability and reliability of income sources
$(1-\beta_1)$ of the households do not anticipate a better profit of the second-season cultivation so they grow only once a year and migrate in the dry season			Reducing the migration rate from $(1-\beta_1)$ to $(1-\beta_2)$ in the promotion year	Short-term social status—the confidence to make an improvement
			Maintaining the migration rate at $(1-\beta_3)$ 2 years after the promotion year	Long-term social status—the household stability and sense of security and self-sufficiency

[a]The promotion activities include holding community discussions, visiting each household in person, giving training on second-season cultivation, and strategies to conserve water, etc. As Kudagaon is a small village with only 85 households, SEs are able to visit and interview each household.

Table 3 Transitions between different states for an agent

Transition	Meaning
$S_1 for1S \xrightarrow{\beta_1} Season2$	Before SEs' promotion, with probability β_1, a one-season cultivation household will change to two-season cultivation. $\beta_1 = 5\%$
$S_1 for1S \xrightarrow{(1-\beta_1)} MigrationWork1$	Before SEs' promotion, with probability $(1-\beta_1)$, a one-season cultivation household will do migration work during the dry season
$BeingPromoted \xrightarrow{\beta_2} Season2$	During the SEs' promotion year, with probability β_2, a household being promoted will change to two-season cultivation. $\beta_2 \gg \beta_1$
$BeingPromoted \xrightarrow{(1-\beta_2)} MigrationWork2$	During the SEs' promotion year, with probability $(1-\beta_2)$, a household being promoted will migrate during the dry season
$Harvest \xrightarrow{\alpha} Profit$	With probability α, a household will reach the anticipated profit through second-season cultivation and decide to do two-season cultivation next year
$Harvest \xrightarrow{(1-\alpha)} NoProfit$	With probability $(1-\alpha)$, a household will not reach their anticipated profit through second-season cultivation and decide to do one-season cultivation next year
$S_1 for1SAfter \xrightarrow{\beta_3} Season2$	After the SEs' promotion year, with probability β_3, a one-season cultivation household will change to do two-season cultivation. $$\beta_3 = \beta_2 \cdot \alpha \tag{1}$$
$S_1 for1SAfter \xrightarrow{(1-\beta_3)} MigrationWork2$	After the SEs' promotion year, with probability $(1-\beta_3)$, one-season cultivation household will migrate during the dry season

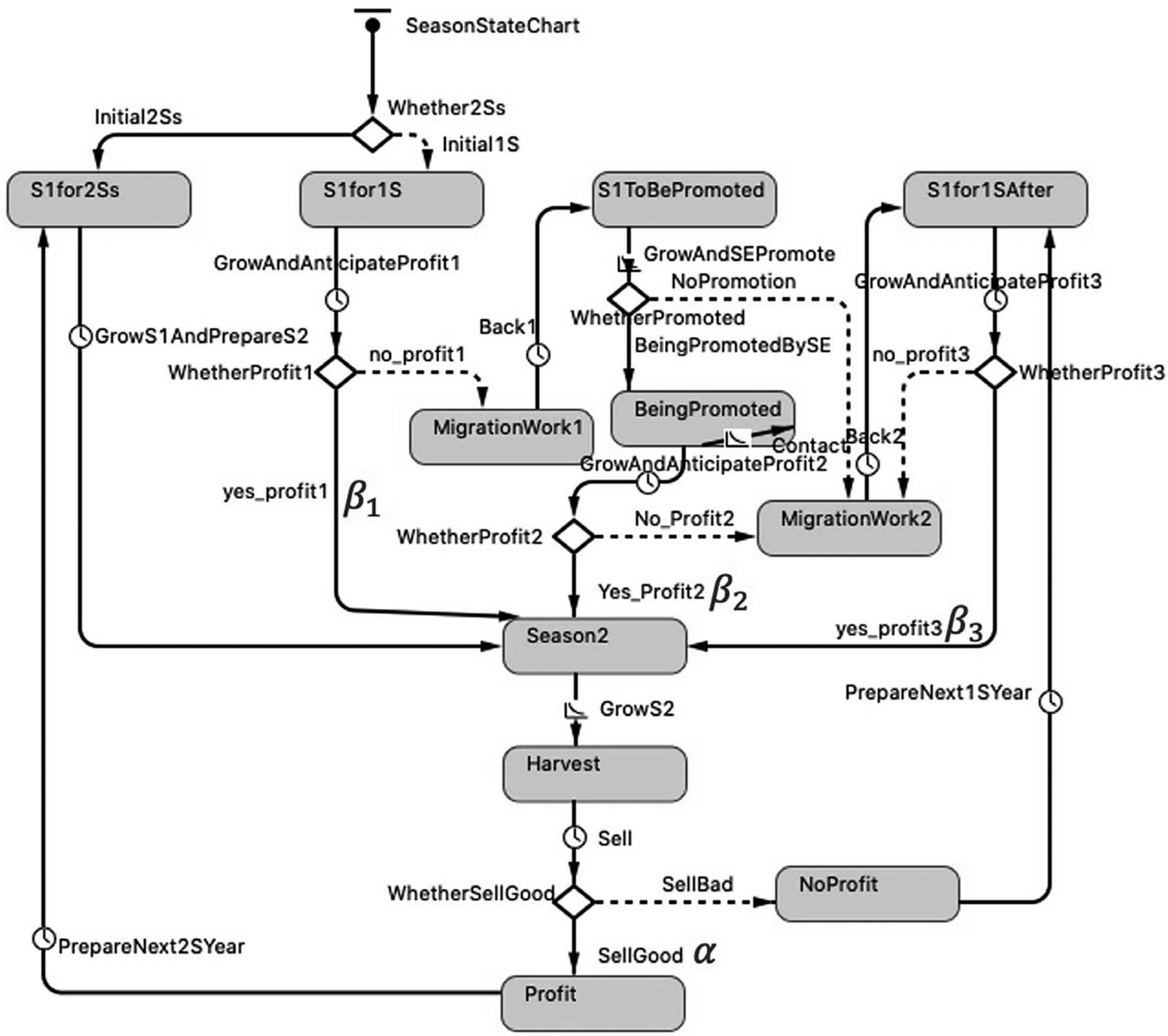

Fig. 3 The flowchart of the agents' state transitions

and, in the long term, the SE wants to improve β_1 to β_3. β_1 is a given static rate based on historical data. β_2 and β_3 are targets that the SE wants to reach. There are different scenarios of β_2 and β_3. In this paper, we offer suggestions on promotion efforts and their durations to reach each scenario of β_2 and β_3.

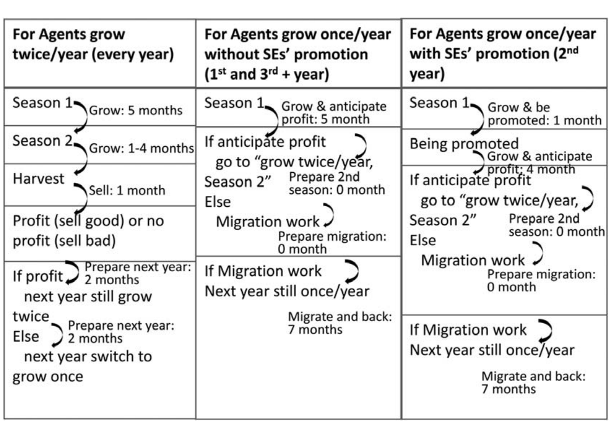

Fig. 4 The trigger conditions and/or the duration of the transitions between the states of the agents

We introduce modeling and scenario development in Sec. 2, discuss the results of the scenario planning in Sec. 3, and summarize our contributions in Sec. 4.

2 Modeling and Scenario Development

2.1 Build the Architecture and Set the Baseline Scenario of the Agent-Based Model. To capture the factors that impact the

Table 4 Scenarios for test each factor

Factors	Scenarios
Network structure	Distance-based Scale-free
Promotion effort	Different percentages of households being promoted—10%, 50%, 75%, 100%
Promotion duration	Different promotion durations—1 month, 2 months, 3 months, 4 months
Anticipation	Different positive anticipations of second-season profit—75%, 95%
Profit	Different percentages of households who actually obtain higher profit—75%, 95%

Table 5 The expected outcome of the scenario planning and the way to obtain such outcome

Expected outcome	The way to obtain the outcome		
Simulation results		Short-term effect	Long-term effect
	Improved economic state	The number of households that gain expected profit by growing twice a year in the *promotion year*	The number of households that gain expected profit by growing twice a year in *the fourth year*
	Improvement of social status	The number of households that migrate during the dry season during the *promotion year*	The number of households that are directly or indirectly promoted
Critical factors	Identify whether the simulation results are sensitive to scenario changes for each factor		
Variability of the simulation results	By changing the scenarios of the critical factors, obtain the range of the output of the model		
Identify how the critical factors affect the simulation results	Capturing qualitative and quantitative relationship among critical factors		

promotion effects, we simulate the households' behavior using ABM. The simulation is performed using AnyLogic 8 PLE software. Because Kudagaon is a single community with a relatively flat social hierarchy, we define each household as an agent and use a single type of agent. Social influence and influence of each household's neighbors are randomized in the same numerical range, although they vary from household to household.

The project's duration is 3 years. We simulate the households' behavior for 4 years. To establish a baseline, there is no intervention in the first year to simulate the villagers' behavior before the project

Table 6 The summary of the results of the scenario planning

Factor	Controllable or not	Scenario	Meaning	Observation	Whether critical or not
Network type[a]	No	Distance-based	One community with strong neighborhood influences but weak or zero distant interactions	The scale-free network has slightly better results in the promotion year, but in the long-term, network type does not affect the promotion result; see Figs. 5 and 6	No
		Scale-free	One community with asymmetric influences between any two connected households and the influence does not depend on distance		
Promotion effort	Yes—SEs can control the promotion effort by reaching out to different numbers of households	Reaching different numbers of households: 10%, 30%, 50%, 75%, 100%	The promotion condition and target can be different from village to village, so searching for an appropriate rate for each village is necessary to reduce the promotion cost	The promotion result is always improved by increasing the promotion effort. The short-term effects are more sensitive to the promotion effort than the long-term effect; see Figs. 5–7, and Table 7	Yes, more critical for short-term effects
Promotion duration	Yes—SEs can perform the promotion for different lengths of time	The promotion duration may last from 1 month to 4 months during the rainy season	A short promotion means relatively short direct promotion but long indirect promotion. This is suitable for a village with a strong mutual influence among households and vice versa	For short-term effects, long promotion has much better results; for long-term effect, short promotion and long promotion show similar results; see Fig. 8 and Table 8	Only critical for short-term effects
Villagers' anticipation and real profit—β_2 of households anticipates a better profit through second-season cultivation, α of them gain real profit as anticipated	Initially, α and β_2 are uncontrollable, but as the project goes on, SEs can control them by improving productivity, developing more market demand, etc.	$\beta_2 = 95\%$ $\alpha = 95\%$	Optimistic profit anticipation; good economy, weather condition, or soil fertility	The short-term result is more sensitive to profit anticipation; The long-term result is more sensitive to actual profit, see Fig. 9	Profit anticipation is critical for short-term effects; real profit is critical for long-term effect
		$\beta_2 = 95\%$ $\alpha = 75\%$	Optimistic profit anticipation; acceptable economy, weather condition, or soil fertility		
		$\beta_2 = 75\%$ $\alpha = 95\%$	Conservative anticipation; good economy, weather condition, or soil fertility		

[a]A SE needs to determine the network type of a village through observation and statistics. The specific indicators used to determine the network type may vary from village to village.

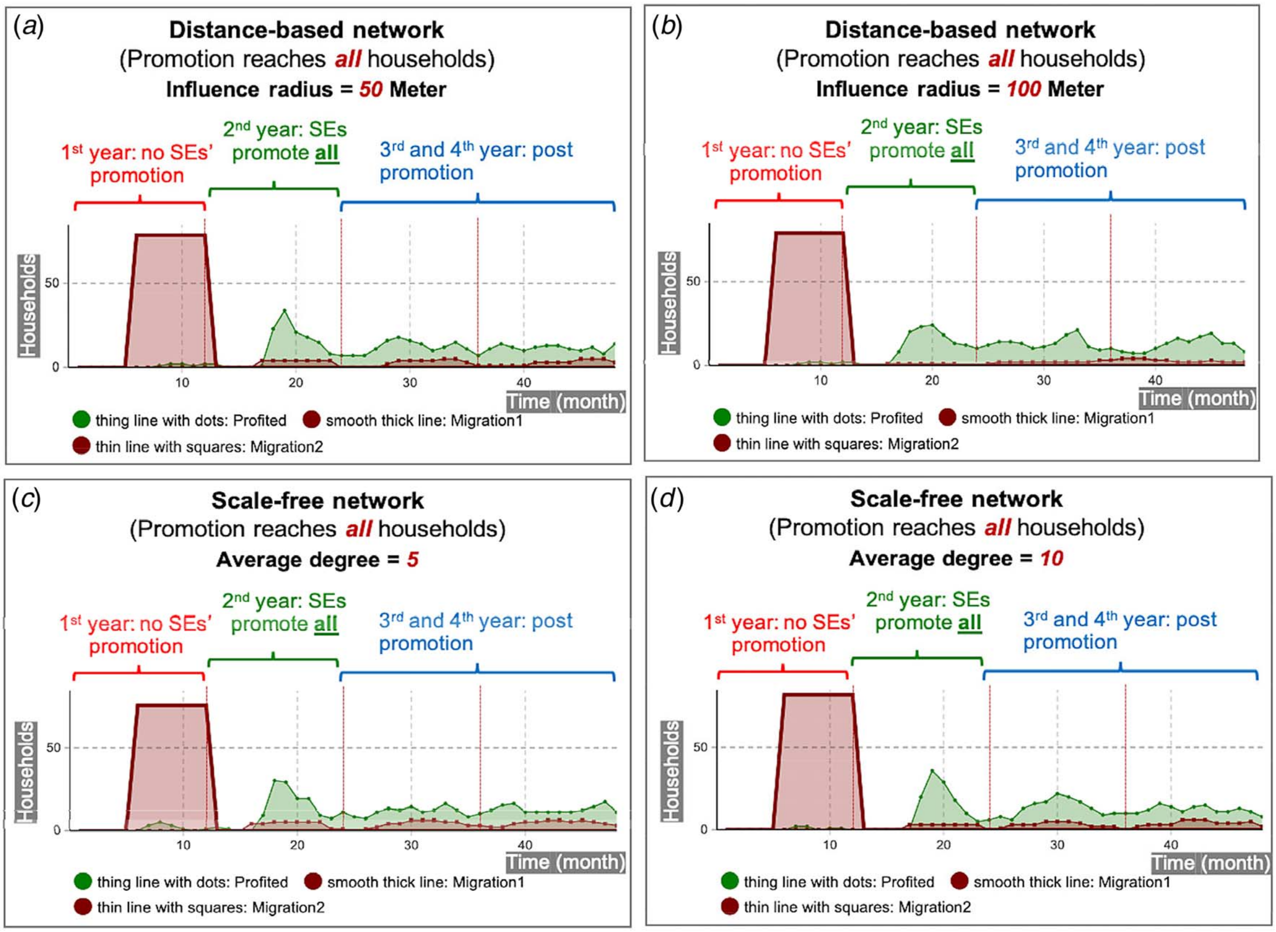

Fig. 5 Results for two network types when promotion reaches all households

launches. This pre-project simulation allows us to verify the model using current actual data. The SEs' promotion starts in the second year which takes place during the rainy season. The third and fourth years are post-promotion. This allows us to track the long-term effects of the SE's promotion.

States and transitions between states: An agent (household) has 11 possible states, as follows.

$S_1 for1S$ Growing once a year before SEs' promotion

*MigrationWork*1 Migrating during the dry season, before the promotion

$S_1 ToBePromoted$ Growing once a year in the SEs' promotion year

BeingPromoted Being promoted to grow twice a year by SEs

*MigrationWork*2 Migrating during the dry season after being promoted

$S_1 for1SAfter$ Growing once a year after the SEs' promotion year

$S_1 for2Ss$ Growing the first season crops for a two-season cultivation year

*Season*2 Doing a second season of growing in the two-season cultivation year

Harvest Harvesting the second-season crops

Profit Gaining at least the expected profit or even more from second-season cultivation

NoProfit Gaining less profit than expected from second-season cultivation

The transitions between states are described in Table 3. The flowchart of the agents' state transition is in Fig. 3. The trigger condition and/or the duration of each transition is illustrated in Fig. 4.

2.2 Scenario Development. A factor is any source of uncertainty source, including the model structure, initial conditions, and input parameters. In this paper, based on the basic knowledge from the SE, we define the network structure, SE's promotion effort, promotion duration, villagers' anticipation of profit, and actual profit as factors to be explored. Different scenarios are developed for each factor by brainstorming between an employee of SunMoksha, Ayushi Sharma, and research assistants in Systems Realization Laboratory, Lin Guo and Vishnu Kamala, based on their experience, domain knowledge, and assumptions. Through scenario planning, the sensitivity of the results to each factor is analyzed, and critical factors are identified. In Table 4, we list the scenarios related to each factor. The expected outcome of scenario planning and the way to obtain these outcomes are given in Table 5.

3 Results and Discussion

We explore the network type, promotion effort and duration, and anticipation level of profit and actual profit level. The results indicate that the acceptance of second-season cultivation is insensitive to network type but is sensitive to promotion effort. The factors that particularly affect the short-term result are promotion duration and villagers' anticipation; the factor that affects the long-term result is the real profit that second-season cultivation actually produces. In Table 6, we summarize the results of the scenario planning. We describe our exploration process and observations in detail in Secs. 3.1–3.3.

3.1 Exploring the Network Type and Promotion Effort and Their Interaction Effects. The SE wants to reduce the migration population and increase the profit population. In Figs. 5 and 6, we present the results of two network types when the SE's

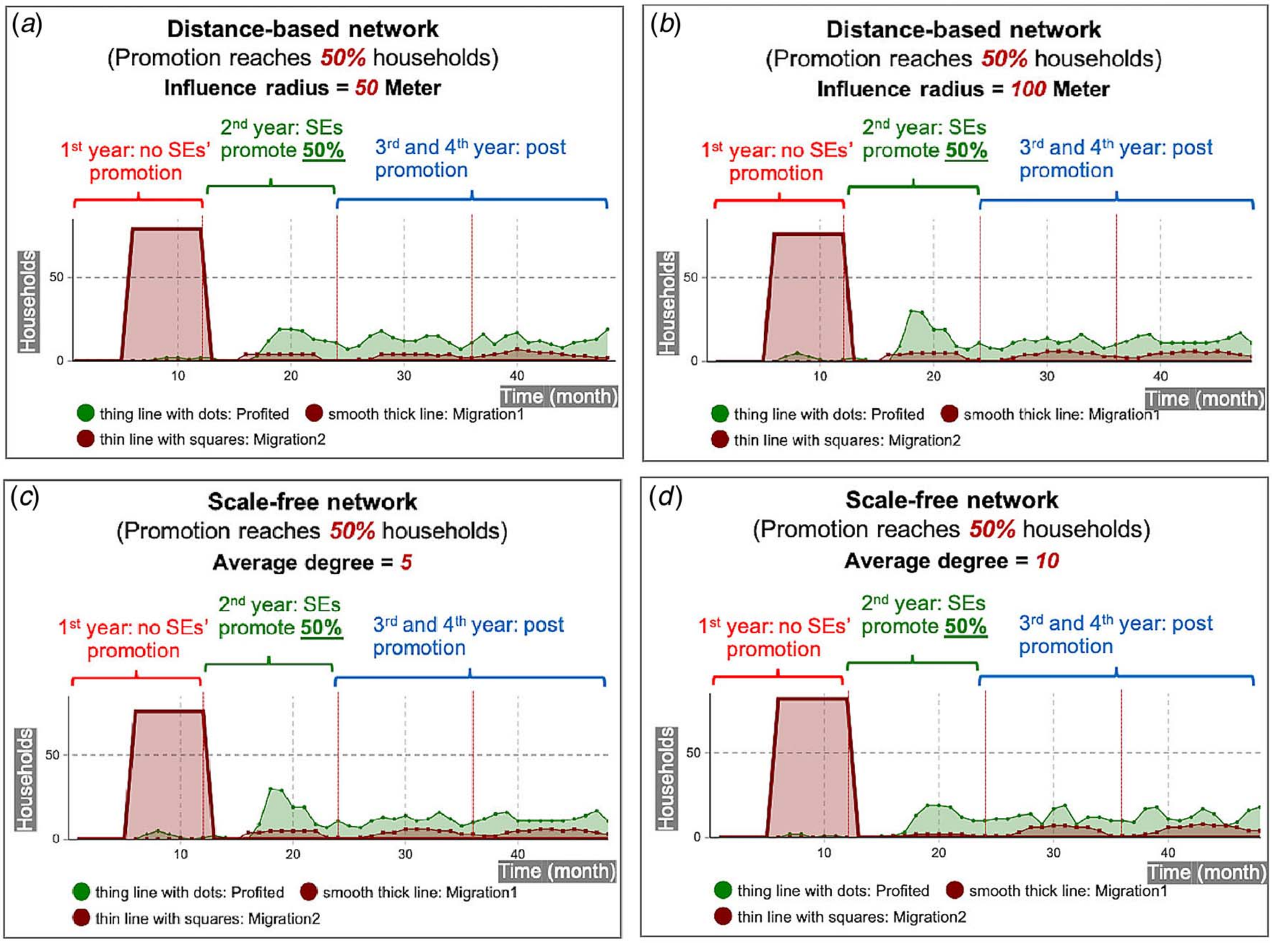

Fig. 6 Results for two network types when promotion reaches 50% households

promotion reaches every household and 50% households, respectively. In each graph, the horizontal axis represents time (unit: month), and the vertical axis represents the number of households. The smooth thick line represents the number of migration households during the dry season in the first year, the thin line with dots represents the households that gain expected profit from second-season cultivation, and the thin line with squares represents the number of migration households during the dry season in and after the promotion year (the second, third, and fourth year).

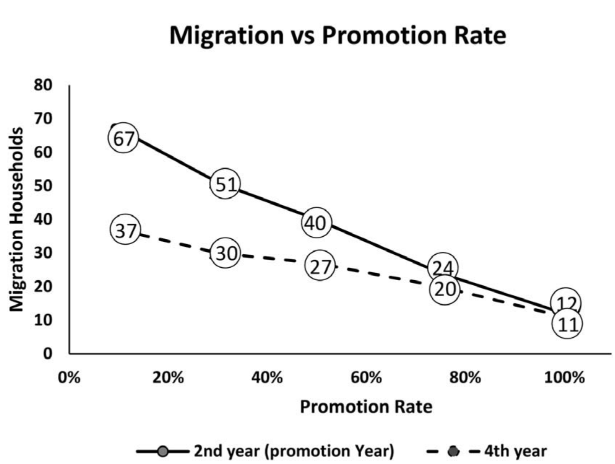

Fig. 7 The migration households with different promotion effort

We explore different influence radii of the distance-based network, 50 m (Fig. 5(*a*)) and 100 m (Fig. 5(*b*)). We explore different average degrees of the scale-free network, 5 (Fig. 5(*c*)) and 10 (Fig. 5(*d*)), that is the average number of connections of each household. We also explore two different promotion efforts, reaching all households and reaching 50% households (the households can promote each other through the network), with 1-month duration.

Observations from exploring the type of network (comparing Figs. 5(*a*) and 5(*b*) with Figs. 5(*c*) and 5(*d*)): neither the short-term nor the long-term results are sensitive to network types.

Observations from exploring the influence radius (comparing Fig. 6(*a*) with Fig. 6(*b*)): if the village is a distance-based network, when the influence radius is larger, the short-term effect is slightly better, whereas the long-term effect is insensitive to the influence radius.

Observations from exploring the average degree of the network (comparing Fig. 6(*c*) with Fig. 6(*d*)): when a village is a scale-free network, neither the short-term nor the long-term results are sensitive to the average degree, the average number of connections of each household.

Observations from exploring interaction effect of network type and promotion effort: only the short-term results are sensitive to promotion effort, whereas the long-term results are insensitive to the promotion effort because in long term, the households promote each other sufficiently.

In Fig. 7, we illustrate the number of migration households during the promotion year (the short-term effect) and 2 years after the promotion year (the long-term effect). As the promotion rate increases, the marginal improvement in the short term is greater than that in the long term. In Table 7, we list the interaction effects of influence radius and promotion effort. Even if the SE

Table 7 Promotion effort exploration—migration household in the promotion year and in the end-of-project year with different network scenarios

	Promotion effort									
	10%		30%		50%		75%		100%	
Type and setting of the network	2nd year	4th year	2nd year	4th year	2nd year	4th year	2nd year	4th year	2nd year	4th year
Distance-based network With influence radius: 50 m	67	37	51	30	40	27	24	20	12	11
Distance-based network With influence radius: 100 m	66	37	51	28	40	27	26	20	9	13
Scale-free network With the average number of connections for a household being 10	68	40	62	37	44	26	27	22	12	12

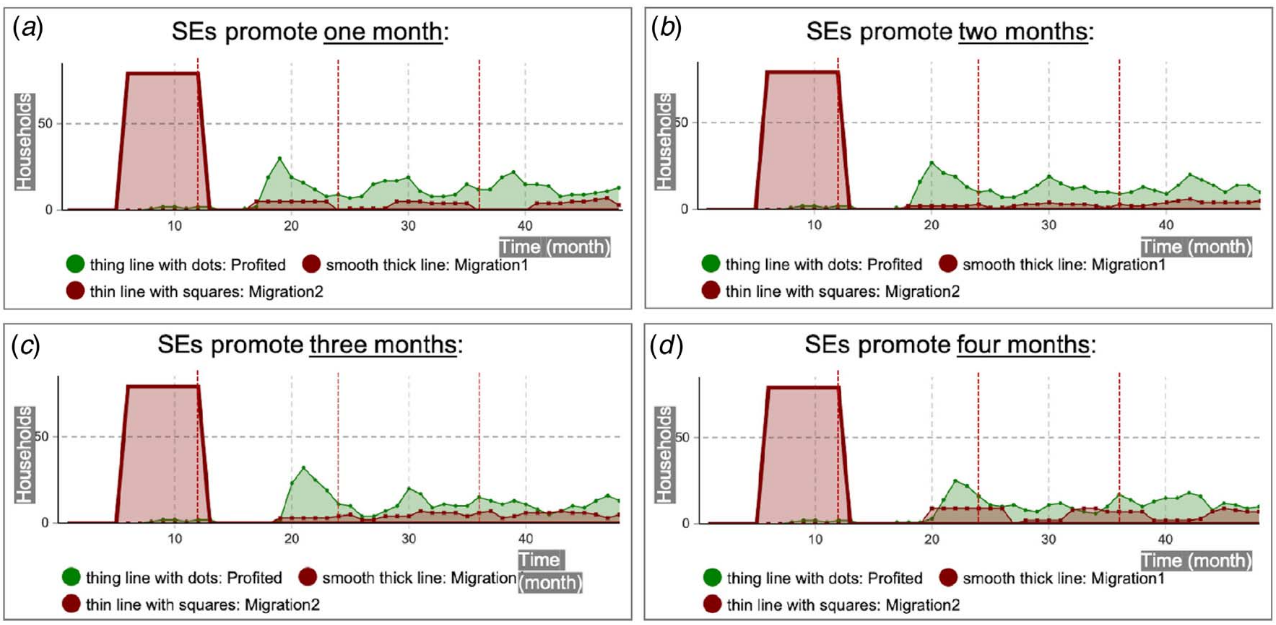

Fig. 8 Simulation results for different promotion durations—using a distance-based network with a 75-m influence radius

promotes every household, there will still be 11–13 households migrating during the dry season.

Exploring promotion effort and its interaction with influence radius: with the consideration of various promotion efforts, the simulation results are still insensitive to the types of network and are not sensitive to the network setting either. The migration population is reduced with the increase of promotion effort. To save cost, a SE can select the appropriate promotion effort (given a certain target for population migration) instead of promoting every household and the economic and the social status can be increased.

3.2 Exploring the Promotion Duration. In Fig. 8, we show the promotion results with different durations—1 month (Fig. 8(*a*)), 2 months (Fig. 8(*b*)), 3 months (Fig. 8(*c*)), and 4 months (Fig. 8(*d*)). As we have shown that the results are insensitive to the type and setting of the network, we select a distance-based network and a 75-m influence radius. The migration population under different scenarios is summarized in Table 8. The results reveal that prolonging promotion results in larger profit in both the promotion year and the following years. The reason is that a longer promotion results in a larger population being promoted both directly (by the SE) and indirectly (by villagers themselves). Direct promotion together with the indirect promotion reinforces the villagers' acceptance of second-season cultivation. However, when prolonging the promotion from 3 months to 4 months, the results do not improve. This indicates that the villagers' capacity for accepting an idea through promotion has an upper limit; therefore, overwhelming promotion does not bring a higher social acceptance and a 3-month promotion gives the bests results for this village.

Table 8 Migration population (households) during the 4 years with different promotion durations

Promotion duration	1st year	2nd year (promotion year)	3rd year	4th year
1 month	80	1–10	1–11	1–9
2 months	80	10	1–9	1–10
3 months	80	0–1	1–9	2–9
4 months	80	0–2	1–8	2–9

Exploring promotion duration: prolonging the SE's promotion allows more interactions among the SE and the villagers and also triggers more indirect promotion among villagers. Therefore, it enhances the acceptance of second-season cultivation. Thus the value of increasing the duration of promotion has an upper limit. In this project, this limit is 3 months—after 3 months, additional promotion does not does not help.

3.3 Anticipation and Profit Exploration. Another two factors are the villagers' anticipation of profit and the actual profit they gained in the previous year. These are important because the SE needs to set a target for the two factors when doing promotion.

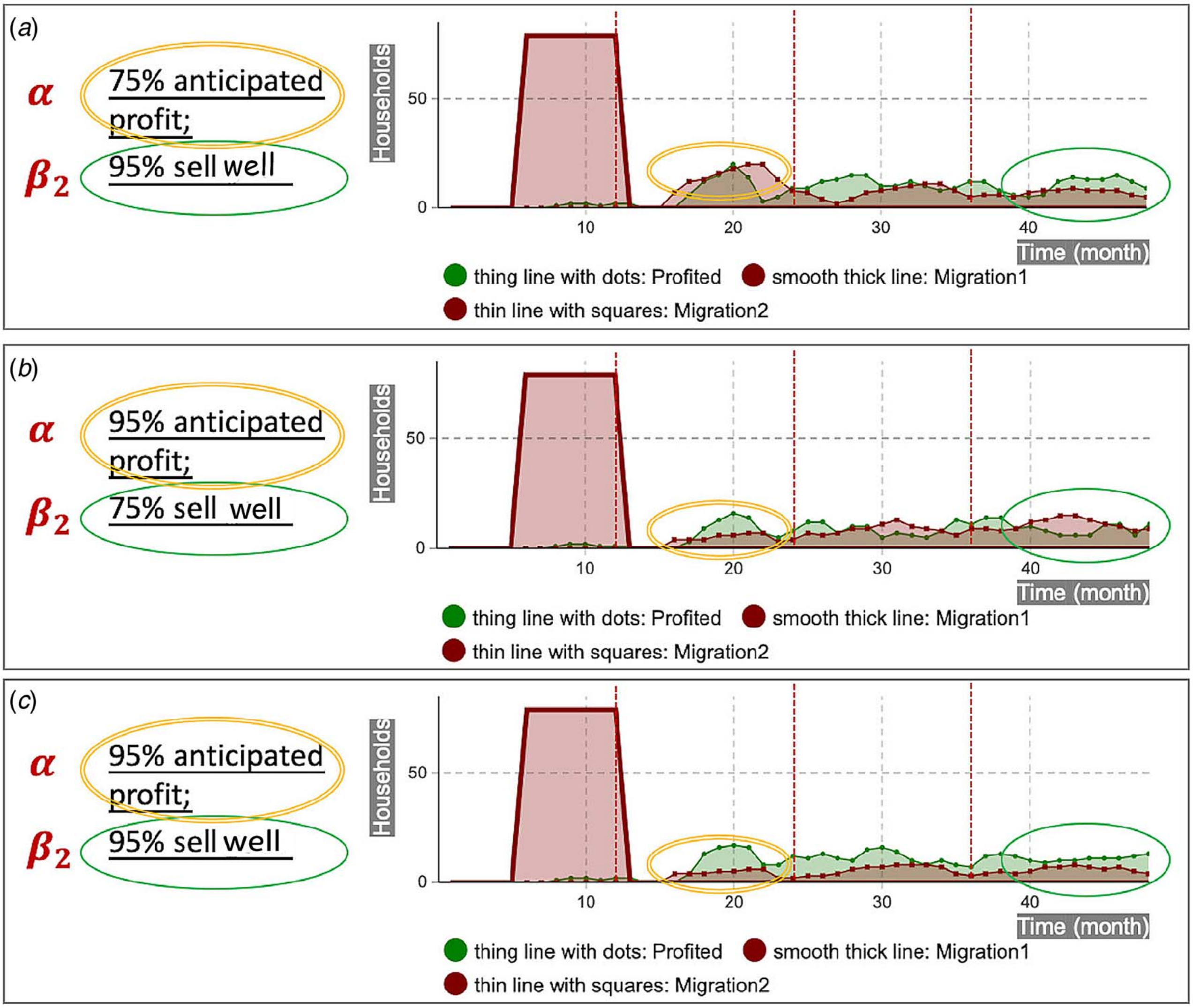

Fig. 9 Simulation results of three scenarios of anticipation β_2 and profit α

Therefore, we need to identify the relationship: (1) between the villagers' anticipation and their actual improvement of actual economic and social status and (2) between the villagers' profit and their decision on whether to do two-season cultivation the next year.

We explore three combinations of two values of α and β_2. Because $\beta_3 = \beta_2 \cdot \alpha$, we do not need to set a value for β_3. We use a distance-based network with influence radius as 75 m and the SE promotes 50% households. The long-term effect is determined by the short-term effect and the real gain. In Fig. 9, we show the results from the three scenarios for α and β_2.

Exploring the relationship between the anticipation of profit and the actual profit: the short-term result is more sensitive to anticipated profit; the long-term result is more sensitive to actual profit. A SE can select the appropriate target for anticipated profit when promoting, and take other actions such as improving farmland productivity, expanding market share, or reducing inventory and logistics costs to improve farmers' actual profit to reach the desired migration rate target.

4 Closure

In this technical brief, agent-based modeling is used to simulate villagers' acceptance of second-season cultivation, and scenario planning is used to identify critical factors that significantly affect the results. We explore scenarios for four factors: network type of the village, the SE's promotion efforts, the SE's promotion duration, and the villagers' anticipated profit and actual profit, with respect to the short-term and long-term effects on villagers' economic and social status. We observe that among all the explored factors, the SE's promotion duration and villagers' anticipation are critical to the short-term effects, whereas the villagers' real profit is critical for the long-term effect. A SE can select the appropriate scenario to reach their economic and social goals.

To make this scenario-planning process adaptable for other social-technical-system design projects, we summarize the process as follows:

- Identify the factors in the system with uncertainties.
- Determine whether each factor is controllable or uncontrollable.
- For controllable factors, identify their scenarios and the meaning of each scenario based on data, domain expertise, or assumptions, and identify or suggest the ways of setting each scenario.
- For uncontrollable factors, identify possible scenarios, and connect each scenario with system performance, and predict the impact of each scenario on system performance.
- Analyze the sensitivity of the simulation output to each factor and the necessary combinations of multiple factors.
- Identify critical factors—if the simulation output is sensitive to a factor or a combination of multiple factors, then the factor or the combination of multiple factors is a critical factor.

- Identify the quantitative relations among each scenario of the critical factors and the simulation output.
- Provide decision support to the system designer by giving all the scenario-output relations.

This proposed scenario-planning process allows designers in various fields to perform simulations and identify critical factors in their systems and select specific scenarios that accommodate different site-specific input values or domain-dependent knowledge to reach their goals.

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Conflict of Interest

There are no conflicts of interest.

Data Availability Statement

The authors attest that all data for this study are included in the paper.

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