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Diffusion of development initiatives in a southern Lao community: An agent based evaluation

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ABSTRACT

Development initiatives in poor communities often aim at changing behaviour at the household level. We develop an agent based model to simulate the process of knowledge diffusion that undergirds household behaviour choices. The model is patterned on a rural community in southern Laos and is applied to simulating three development initiatives actually implemented there. The first initiative involves a program to encourage school attendance, the second a campaign to introduce safe water handling practices, and the third an investment in a feeder road to facilitate engagement with markets. The simulation exercise starts with an infusion effort that recruits specific households, then traces the diffusion process through social networks defined by shared activities. The decision to adopt a change in behaviour is based on the relative influence of adoptees vs non-adoptees within a household's network. Further, the degree to which a household opting to change its behaviour effectively realizes a change also depends on the influence of its social network. In actual fact, the education initiative failed in the Lao community while the initiatives involving water practices and market engagement were successful. Our model helps to understand these outcomes in light of the way the initiatives were promulgated within a community social structure.

1. Introduction

Despite a long history of well meaning development and anti-poverty work, progress has been uneven. Laos, for example, remains poverty ridden despite large infusions of development aid, even with recent high economic growth and rising per capita income. While macro-level human development indicators related to health, education, and income show improvement, evidence at a more micro level points to remaining problems. This has raised the alarm as to "who has been left behind in human development progress – and why" (UNDP, 2016).

Program design may be part of the problem. Development initiatives tend to be applied in generic ways based on successes in particular localities. Further, benefits of a project as measured in the aggregate may, in fact, be largely captured by particular groups or individuals while failing to permeate the broader community. Perhaps the benefits are concentrated at the infusion point of the initiative. Or maybe investment in, say, a power plant supports industrial development while nevertheless leaving neighboring homes without electricity. Or a model farm shows high returns yet fails to change the behaviour of local famers bound to traditional ways. Broad-based, balanced development has not been achieved, yet standard cost-benefit approaches to project evaluation may fail to reveal program deficiencies (ADB, 2013).

We submit that an impediment to improved program design lies with evaluation methods that focus on broad outcomes to the neglect of understanding the way in which interventions are received by communities. Methodologies that track outcomes typically measure the impact of programs on indicators such as poverty, education, or health (see Warr, 2010;

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Alkenbrack & Lindelow, 2015), and may involve cost-benefit analysis to arrive at bottom line measures of net return (see ADB, 2013; Manivong & Cramb, 2008). Such assessment methods certainly have their place. However, they cannot capture how and why particular elements of the population benefit more, less, or not at all from a development initiative. This requires additional analytical tools to get at the process by which the initiative diffuses through the community (Kruk & Freedman, 2008).

In this paper, we develop an analytical technique aimed at understanding the diffusion process of a development initiative. The technique involves agent based modeling to capture the decision-making process of households within the context of their social networks. We apply the approach to three different development initiatives to examine how each initiative diffuses into the community. This allows us to understand why some individuals may be reached under one program design but missed under another. With that, it aids us in judging the best manner of infusing an intervention into a community given that community's unique social network structure.

Our model depicts a virtual society, akin to a village in southern Laos. We use household survey data from the village to calibrate household and network attributes. Agents are characterised by their initial endowments of wealth and connections which will determine how they respond to change. Applying the calibrated model, we trace the diffusion paths of behaviour change and associated household gains in welfare. We then compute aggregate gains, both for the community as a whole and for different socio-economic tiers. This allows us to evaluate the penetration of our three development initiatives into the community, particularly with respect to their reach among the poor.

The particular pathways through which a development initiative impacts a community and the barriers the diffusion process encounters determine the structure of benefits among community members as well as an outcome in the aggregate. The nature of these pathways and barriers is particular to a given community. Thus poor project outcomes in one locality should not be presumed to invalidate a given strategy in any general way. Applied in another community, the same strategy might achieve a more successful result. Indeed, even applied in the same time and place, but with a different point of infusion, the end result might differ. Recognition of this is important for Laos and other less-developed economies characterised by substantial differences in social structure across communities.

2. Agent based modeling

Agent based modeling (ABM) incorporates elements from sociology (how people interact and form overlapping networks within a society), psychology (assumptions about behaviour drawn from an understanding of the human mind), and economics (game-like responses to choices based on a framework of objectives and expectations formation). ABM involves imagining virtual 'players' as individual agents. These agents are ascribed heterogenous characteristics, for example, with respect to preferences and endowments of wealth or knowledge. They are then allowed to interact within specified limits, determined, for example, by resource constraints, within an environment comprised of other agents and established rules of engagement. The ABM approach allows the analyst to trace how agents respond to an intervention, or even to knowledge of an intervention. It then reveals the pattern of benefits that results. The model captures an iterative process that occurs over time yielding an outcome marked at a moment in time – an emergence, rather than an equilibrium.

ABM originated in the realm of artificial intelligence. It arose from the need to create 'synthetic environments' for experiments of a sort that would be infeasible or unethical in real life, for example, for training in air traffic control or understanding the spread of infectious diseases (Bandini, Manzoni, & Vizzari, 2009; Horio, Kumar, & DeCicco, 2015; Funk, Salathé, & Jansen, 2010). ABM has been a relatively slow entrant to the field of economics, and is rarely if ever seen in the economics of development. Yet it would seem a natural fit in economics, a discipline in which direct experimentation is difficult.[1] ABM techniques offer potential for interpreting such economic phenomena as consumer choice (LeBaron, 2000) and the diffusion of technologies (Bonabeau, 2002). ABM highlights the interaction among heterogenous agents in response to an exogenous shock. It explores the agents' reactions, which depend on their incentives and endowments as well as on features of their environment (Holland & Miller, 1991; Hanappi, 2017).

Conceivably, the non-replicable 'bottom-up' nature of ABM may have slowed its adoption in economics. Yet the approach has been widely taken up in the natural sciences which also generally abhor nonreplicability. In any case, econometrics remains the economist's preferred means of estimating relationships, while cost-benefit analysis stands as the tool of choice for policy evaluation. We employ the ABM approach as a complement to these standard analytical approaches. It adds to our understanding by illuminating the process that transpires between an intervention and an outcome. With this, the method aids policy formulation by bringing attention to the infusion point of an intervention and the role played by social networks.

[1] For exploration of ABM techniques within economics and other social sciences, see Holland and Miller (1991), Bandini et al. (2009), Tesfatsion (2002), O'Sullivan and Haklay (2000), LeBaron (2000), Gotts, Polhill, and Law (2003), and Hanappi (2017).

In our agent based model, we integrate agent to agent interaction and word of mouth learning into a community social network.[2] Considering development programs in this way, the heterogeneity of individual interactions becomes foundational, as in other ABM applications such as the spread of infectious diseases or the diffusion of technology.[3]

Our project site in rural southern Laos consists of a collection of remote villages linked to a town centre by a major road, the East West Economic Corridor. Trading activity connects the villages economically. Disparity in wealth exists among households within villages as well as across groups of villages (*ban*). Some households are geographically dispersed away from villages but still lie within the more encompassing unit of the commune (*moo*). Our results indicate that local household networks, embedded in a social and cultural milieu, influence the inclusiveness of any development initiatives. More specifically, the reach of benefits to poor households is found to depend on network configuration and the point of infusion of the program.

The inspiration for this paper arose from the author's sense of contradiction between formal measures of development success at commune level and direct observation within the villages. For example, an official report maintained that villagers had access to groundwater, yet coloured plastic buckets being carried to and from the river were much in evidence. Moreover, children were missing school to help with water transport and to hunt snakes or rodents for basic sustenance. Although officially the commune was classified as exclusively rice growing with supplemental handicraft production, few young women were seen in the rice fields in the mornings even as they were clearly present later in the afternoon having returned from selling vegetables in the village. The discrepancy between what was being reported (what was supposed to happen) and what was witnessed on the ground speaks to a failure of program assessment and management. We aim to overcome this problem with an approach that is more granular in capturing how development programs deliver benefits and report results.

We proceed by first outlining the three development initiatives to be compared and then describing our Lao subject community and its trading networks. This is followed by a summary of the formal data upon which the simulation is built. We then present the analytical framework and report results of the simulations. We conclude by discussing the value and limitations of our methodology and the implications for policy.

3. Three development initiatives

Three development initiatives are to be compared using our finely textured approach to evaluation: 1) a Laotian government 'education for all' program; 2) a United Nations Development Program (UNDP) 'clean water' campaign (UNDP 2008); and 3) an Asian Development Bank (ADB) road investment project aimed at 'bringing the market to the poor' (ADB, 2010). For simplicity, we label these *Education*, *Water*, and *Market*. While all three initiatives were aimed at alleviating poverty and reducing inequality, and all three were based on established models of program delivery, they differed in their approaches to reaching targeted groups.

The Lao government *Education* initiative involved a top-down approach. Implementation was via a process of consultation between a central government authority (a representative from the Ministry of Education and Training) and village-level educators (teachers and principals). This small and closed consultation group, and the indirect method of delivery to village households, arguably contributed to the limited success of the campaign.

By contrast, the UNDP *Water* campaign adopted a bottom-up strategy of spreading information and improving practices for handling drinking water. UN personnel reached out directly to villagers at the critical locus of activity, the river's edge where the villagers drew water. The campaign thus reached the targeted population with no intermediary.

Finally, the ADB investment in *Market* access involved construction of the East West Economic Corridor (EWEC) intended to connect rural producers to regional and even global markets. Unfortunately, such major road construction projects linking major urban centers often fail to economically engage the small communities en route, concentrating gains instead on the heavy-vehicle based export sector. Within the particular social and trading networks of our Lao community, however, those without vehicles were able to take advantage of the new infrastructure by entering into commercial relationships with those in the village who possessed means of transport. The project thus appears to have been successful in reaching the targeted low income population. Why in this case a highway investment was successful in improving the lives of the rural poor when so often such projects fail to achieve this goal is precisely the kind of question our modeling approach is designed to address.

As with the road construction project, success in reaching the target population under the UNDP water project was not a foregone conclusion. Prior provision of water taps in the villages might have seemed like a surefire way to relieve villagers of the daily drudgery of carrying water from the river. Yet projects that may appear to offer easy benefits can be unexpectedly stymied by local cultural or political conditions. In the provision of water taps, status and convention dictated that the taps be located at the homes of the village chiefs. In some villages, this seems to make no difference as everyone is granted access to the water supply. In other villages however, the location of the taps on the chief's property accords him de facto property

[2] See Banerjee (2004) and Ellison and Fudenberg (1995), among others for 'word of mouth' learning; Jackson (2008) and Goyal (2005) for network games and learning games in networks, respectively; Epstein (1999) and Tesfatsion (2002).

[3] See, for example, Bandiera and Rasul (2006), Besley and Case (1993), Feder, Richard, and Zilberman (1985), and Miguel and Kremer (2003). However, due to the focus on outcomes, these studies tend to miscalculate the rate of adoption (for instance, the adoption of high yield seed varieties) or the resultant level of output. For example, see Munshi (2004); Conley and Udry (2004).

rights. The tap becomes his to control and dole out access as he pleases. The outcome might be better were markets to be established in water access. Tap water could then be sold to villagers, even if at a monopoly price, to achieve broader dissemination. Under the right circumstance with respect to social and political organization, such market development may actually occur spontaneously. But this was not the case for tap water in our study villages.

By contrast, a market outcome did materialize in our community in connection with road transport, with broad consequences for improvement in living standards. Our model is designed to reveal the reasons for such contrasting outcomes by capturing the workings of complex social networks. Our analysis sheds light on how a development initiative transmits benefits within a community, and thus affords assessment of alternative ways of structuring the infusion of the initiative into the community. The analysis rests on a model of the functioning of social networks within the community. With this apparatus at hand, more nuanced evaluation of projects, such as the three described herein, becomes feasible. Ultimately, the capacity to undertake such evaluations offers the prospect of better designed poverty alleviation programs that are more effectively tailored to individual settings.

Table 1
Summary of household characteristics.

Respondent/household characteristics	# of 'yes' responses	% of total
Gender		
female	25	43.1
male	33	56.9
Dwelling		
brick and hardwood (Tier *A*)	9	15.5
softwood and hardwood (Tier *B*)	21	36.2
softwood/straw/makeshift (Tier *C*)	28	48.3
Livestock		
cows/buffaloes	9	15.5
pigs	22	37.9
chickens	48	82.8
other poultry (ducks/turkeys)	1	1.7
nothing	10	17.2
Non-Subsistence Production		
rice	15	25.9
vegetables	27	46.6
timber	8	13.8
other crops	17	29.3
handicrafts	34	58.6
non-farm rural work	11	19.0
community service (church/civic)	21	36.2
processing (rice)	3	5.2
retail (roadside/mobile/market stores)	10	17.2
Vehicle Ownership		
car, truck, utility	4	6.9
motorbike	16	27.6
bicycle	29	50.0
cart (pulled by bicycle or person)	7	12.1
nothing	22	37.9
Formal Education/Training		
training	16	27.6
higher secondary	10	17.2
lower secondary	10	17.2
primary	16	27.6
5 years	13	22.4
3 years	10	17.2
nothing	1	1.7
Other Endowment		
access to media (print/mass)	36	62.1
access to information	35	60.3
electricity	13	22.4
access to ground water	6	10.3

4. The southern Lao community

Our research site lies within a remote and impoverished commune in southern Laos.[4] The commune is one of five within the district of Paksong which is located in the rapidly developing province of Champasak. The nearest major population centre is the growing township of Pakse, the provincial capital. Pakse has historic trading links with another rapidly growing area, the Ubon Ratchathani province of northeast Thailand. Pakse's trade with surrounding regions in Laos and across the Thai border is concentrated in agricultural commodities and the products of agro-industry, particularly coffee and tea.

Our commune has limited exposure to outsiders through modest dealings with traders from Pakse involving trade in material inputs and agricultural produce. Overall however, based on our observations, the commune persists in relative economic isolation compared to other communes in Paksong.[5] The disparity is not unusual in a developing economy that is experiencing a rapid transition from agriculture to manufacturing and/or services (see Moore & Donaldson, 2016).

The commune encompasses 94 villages, with a total population of about 43,000. The district as a whole is not officially classified as poor, with only 16.9 percent of residents falling below the poverty line. However, our commune is clearly less prosperous than others in the district. New economic promise has come to the commune with construction of a seven kilometre feeder road that connects it to the East West Economic Corridor that runs from Cambodia through Pakse to Thailand. Our sample of households is drawn from five villages of the commune that are located along this feeder road. The Economic Corridor and feeder road provide a conduit for inter-provincial trade in goods, services, and information. Prior to construction of the feeder road, the commune could not be accessed during heavy rain which meant villagers were regularly cut off from selling their produce in town.

Our simulation model is constructed based on the profiles of 58 households.[6] Characteristics of these households are summarised in Table 1. Nearly half lived in dwellings of poor construction (softwood/straw/makeshift). More than 80 percent owned chickens, but only 15 percent owned cows or buffaloes. Agricultural production was quite varied with crops ranging from rice to vegetables to timber to miscellaneous other crops. More than half of households engaged in handicraft production and more than a third were involved in community service, either church related or civic in nature. Only four of the 58 households owned a car, truck, or utility vehicle while 16 owned a motorbike and 29 a bicycle. Only 20 households had a member with some degree of secondary education. Only 13 had electricity and only six access to groundwater.

Our interest is in understanding the process by which 58 such diverse households, functioning within their social networks, responded to the three development initiatives introduced into their community (*Education*, *Water*, and *Market*). The *Education* initiative involved a 'top-down' directive from the central government calling for mandatory 100 percent attendance at school. This was communicated by a government official who convened a district meeting with teachers and principals. The purpose was to implant the ideal that children would benefit from attending school and that school attendance must be enforced.[7] It was expected that teachers would return to their respective village schools and propogate the desired behaviour among the villagers.

The five villages from which our sample is drawn shared two schools and seven teachers. The infusion strategy focused on a small, influential group of agents, the teachers and principals. Children and parents learned to repeat the decree that all children were to attend school, every day and for the whole day. Our interviews revealed that the campaign was successful in inculcating a rote knowledge of what was required by the central government, but not in achieving comprehension as to why this was important. As a result, appearances came to be all that mattered, even among teachers, who routinely recorded absent students as attending. In effect, the campaign succeeded in form, but failed in substance.

The *Water* strategy was part of a UNDP effort to bring about improvements in health and hygiene practices in the face of inadequate public health infrastructure.[8] The campaign involved aid workers setting up focus groups with village heads and villagers. The aim was to teach people who collect water from the river and the open wells to boil the water before drinking and to use rust-proof vessels. Recruitment of villagers into the focus groups took place at the locus of activity, the river bank, and as such was highly effective. In the group sessions, plastic buckets were handed out. Our household survey showed that the 52 households who lacked access to a functioning tap or covered well were spread across all five villages and came from different social groups. This approach of direct engagement at the locus of water collection enabled effective reach to the target population. As a result, the program succeeded in changing water collection practices, with most villagers using the plastic buckets provided (some even with cracks and holes diligently mended with tape). Unfortunately, there was no provision in the UNDP program to replenish the supply of buckets as they wore out, and many villagers reverted to using old rusty tins. However, the program was vindicated inasmuch as all villagers we surveyed understood and followed the procedure of boiling water before drinking.

Finally, the *Market* strategy was part of an ADB infrastructure development program aimed at facilitating intra-regional trade. One of the goals of the program was to connect rural producers with urban markets by improving access through

[4] The commune is not identified as the author promised confidentiality to the villagers and the district officer.

[5] Distict officials were vague in interviews about the specifics of economic development in the commune and district.

[6] The simulation methodology can accommodate a much larger number of agents than used in this paper. There is a natural limit (not a computational one) on model size set by networking possibilities.

[7] Universal adult literacy and enrolment at primary and secondary level is one of the major anti-poverty and social development campaigns in Laos. For further discussions, see Chareunsy (2007).

[8] For more on rural-urban disparities in public health infrastructure in Laos, see Chareunsy (2007).

construction of feeder roads to major trunk lines. In our simulation, we consider specifically the sale of horticultural produce in external (commune and district) markets. Market engagement and social networks tend to develop mutually through positive feedback loops. The market functions as a hub connecting buyers to sellers, buyers to buyers, and sellers to sellers. Within such hubs, trade facilitates development of social networks, and social networks in turn foster familiarity and trust to further stimulate business transactions. Villagers who sell their farm perishables or buy inputs or non-farm items in external markets are exposed to new people, information, and opportunities related to their production activities. Through these channels they may, for example, gain access to higher yielding seed varieties or acquire knowledge of better farming techniques. With better roads and growing demand for market visits, households that possessed transport vehicles began to offer services on commercial terms. This enabled growers who had not previously been able to get their produce to the market to do so. Thus the feeder road to the EWEC provided two areas of economic expansion: one, increased interaction among traders, and two, development of transport services activity.

5. Construction of the virtual community

We construct our virtual community 'from the ground up', treating our 58 households as unique individual agents[9] and specifying a decision rule by which they choose to adopt a change in behaviour in response to the influence of others in the community (see Epstein, 1999; Tesfatsion, 2002). For each of the three intervention strategies simulated – *Education*, *Water*, and *Market* – the infusion mechanism and the transmission of influence on behaviour will differ.

We use data from Table 1 to characterize agents. The data include six broad categories of agent endowments or activities (dwelling type, livestock, non-subsistence production, vehicle, education, and other, such as access to water, electricity, etc.) plus sub-categories. We use dwelling type to divide agents into three social tiers: Tier *A* with nine agents (15.5 percent), Tier *B* with 21 agents (36.2 percent), and Tier *C* with 28 agents (48.3 percent).[10] We will be particularly interested in whether a development strategy reaches Tier *C* agents and succeeds in changing their behaviour.

On the basis of given endowments, we construct indicators for each agent, i, to represent relative well-being and network connectivity. The well-being indicator, λ_i, is given by the simple sum of all endowments, $y_{i,m}$, measured dichotomously,[11] relative to the most well-off agent conceivable, i^*, such that:

$$\lambda_i = \frac{\sum_{m=1}^{M} y_{i,m}}{\sum_{m=1}^{M} y_{i^*,m}}. \tag{1}$$

The most well-off agent conceivable would have a brick dwelling, own cows, pigs, and chickens, as well as a car, motorbike, and bicycle, have access to media, electricity, and ground water, and have completed secondary education. The indicator provides an ordinal measure of the well-being of each agent relative to the community. It thus allows us to capture an agent's position within the social hierarchy. Values of λ_i for the 58 agents in our sample are shown in Appendix A. They range from 0.094 for the poorest to 0.750 for the wealthiest.

The network connectivity indicator, ζ_i, captures the density of an agent's connections to other agents. The assumption underlying the indicator is that participation by an agent in an activity creates a network connection with all other agents that participate in that activity. Activities involve such pursuits as animal husbandry, agricultural production, community service, formal schooling, and water collection. The value of the indicator for agent i is calculated as the sum across all activities, x_n, and across all other community members, j, who also participate in the same activities, again normalizing on the most connected agent conceivable, i^*, one that participates in all activities and is thereby connected through each activity with every other agent that participates in that activity:

$$\zeta_i = \frac{\sum_{j=1}^{J-1}\sum_{n=1}^{N} x_{ij,n}}{(J-1)\sum_{n=1}^{N} x_{i^*j,n}}. \tag{2}$$

For instance, an agent that grows bamboo, then weaves bamboo baskets and sells these in the market would connect with an agent that only weaves and sells bamboo baskets in two activities, weaving and selling. Values of ζ_i for all 58 agents are shown in Appendix A. They range from 0.023 for the least connected agent to 0.509 for the most connected.

To compare agents along a single dimension, we create a consolidated measure of well-being, θ_i, as the product of our indicators of wealth and network connectivity such that $\theta_i = \lambda_i\zeta_i$. Values for this measure are also shown in Appendix A and range from 0.028 to 0.368.

[9] Agents can in principle represent individuals or households. An earlier approach to simulating this commune based on agent characteristics and clustering appears in Chareunsy (2012).

[10] Other types of household characteristics could be used to classify the population. We chose dwelling type because it appears to be the most relevant distinction of status in our community.

[11] Monetary values were difficult to ascertain and verify through the interview process.

6. Diffusion of an initiative

For each of our three simulation exercises, the infusion of a new practice begins with an infusion to select agents and is then diffused through a complex web of social connections. For the *Education* strategy, infusion begins with teachers. For the *Water* strategy, it begins with those collecting water at the river. And for the *Market* strategy, the starting point is those involved in commercial growing and marketing of vegetables.

In deciding whether to adopt a new practice, an agent is influenced by how many contacts within its social network have adopted the practice. But these contacts are not all equal in their capacity to exert influence. Following our three tier class structure, well-off agents are assumed to wield greater influence than poorly off agents.[12] We formalize this by assigning a weight of one to contacts from the same tier, then increasing the weight by one for each step up in tier and decreasing it by one for each step down. Thus an agent in Tier *B* would weight contacts from Tier *B* by one, contacts from Tier *A* by two, and contacts from Tier *C* by zero. An agent faces a window of influence for adoption of an activity as the weighted sum of contacts who have adopted the practice and a window of influence for non-adoption as the weighted sum of contacts who have not adopted the practice. Let adopting contacts of agent i be represented by j_α and non-adopting contacts by j_β. The windows of influence for adoption and non-adoption are then given respectively by $\omega_{i,\alpha}$ and $\omega_{i,\beta}$, defined as weighted sums of agents across common network activities:

$$\omega_{i,\alpha} = \upsilon_A\left(\sum x_{ij_{A,\alpha},n}\right) + \upsilon_B\left(\sum x_{ij_{B,\alpha},n}\right) + \upsilon_C\left(\sum x_{ij_{C,\alpha},n}\right) \tag{3}$$

$$\omega_{i,\beta} = \upsilon_A\left(\sum x_{ij_{A,\beta},n}\right) + \upsilon_B\left(\sum x_{ij_{B,\beta},n}\right) + \upsilon_C\left(\sum x_{ij_{C,\beta},n}\right) \tag{4}$$

where υ_A, υ_B, and υ_C are the tier specific weights as determined relative to agent i's own tier status.

Agent i will choose to adopt a practice if the window of influence for adoption is greater than the window of influence for non-adoption: $\omega_{i,\alpha} \geq \omega_{i,\beta}$. For a campaign to be successful, influence must be transmitted broadly through the web of network connections to reach large numbers of agents. If the campaign fails to garner a critical mass of influential and well networked adoptees, it will meet with failure.

The decision tree in Fig. 1 summarizes the iterative process of diffusion following an initial infusion. At $t = 0$, an outsider, j_0 (a government official, UN worker, or trader), recruits select agents from the community to change their behaviour. These agents then enter into their local networked activities in $t = 1$. Each agent observes how many contacts of each status level from within its networks have adopted the behaviour being promulgated. If the agent's window of influence of adoptees is greater than its window of influence of non-adoptees, the agent adopts the behaviour too, and returns to participate in the next round of networked activities as an adoptee. If, on the other hand, the agent's window of influence of adoptees is less

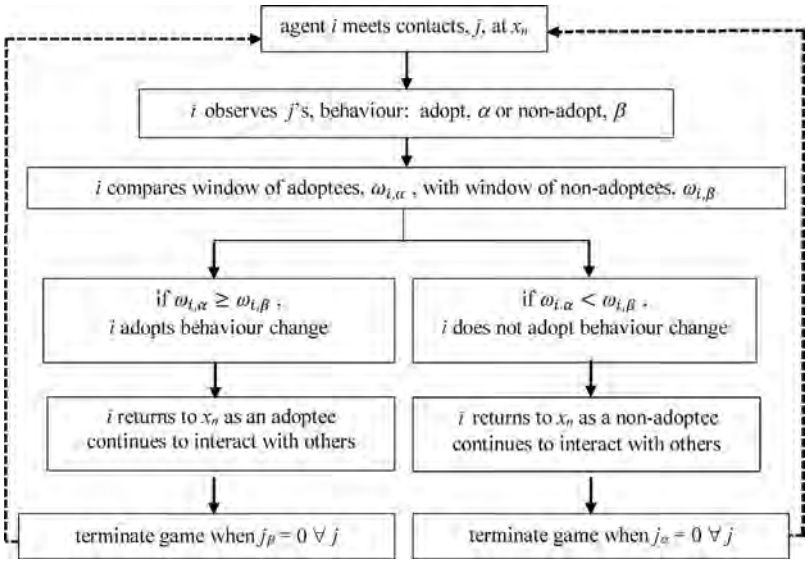

Fig. 1. Iterative decision tree of agent-to-agent interaction and adoption.

[12] For a discussion of this behavioural phenomenon, see Hung and Plott (2001).

than its window of influence of non-adoptees, the agent does not adopt the behaviour, and enters the next round as a non-adoptee. The game ends when all agents' decisions converge to either adoption or non-adoption.

Gains in well-being

Our formulation of gains in well-being that accrue to agents from participating in a development initiative follows the social learning literature, in particular Morone and Taylor (2004). In the same way that an agent's adoption of a change in behaviour depends on the behaviour of other agents in that agent's networks, so too does the agent's derivation of gains depend on the gains of other adoptees of the behaviour. Variation in gains across agents rests on differences in the degree of realization of a behaviour change. An agent learns from other adoptees how fully and consistently to take on the new behaviour, and therefore derives gains in similar measure to other participants. However, the influence of the community is filtered through the agent's own capacity to learn from others and follow through.

Let the gain to agent i in time t, γ_{it}, be additive with the agent's well-being in t (θ_{it}) to determine well-being in t+1, such that:

$$\theta_{i,t+1} = \theta_{i,t} + \gamma_{i,t}. \tag{5}$$

Further, let the agent's capacity to learn and realize a behaviour change be proxied by its level of well-being. The gain to agent i in time t is then given as proportional to all gains received by adoptees of the behaviour in t-1 with that proportion determined by the agent's relative network connectivity (ζ_i) and capacity to realize a change ($\theta_{i,t}$):

$$\gamma_{i,t} = D_{i,t}\theta_{i,t}\zeta_i \sum_{j_\alpha} \gamma_{j_\alpha,t-1} \tag{6}$$

where $D_{i,t}$ is a dummy variable that takes on a value of one if the agent decides to adopt the behaviour change and zero if it decides not to do so.

The outsider arrives to recruit the first round of adoptees bearing full knowledge of the development initiative and full capacity to engage in the prescribed behaviour, as represented by $\gamma_{j_0} = 1$. The agents of the local community are endowed with characteristics that determine their exposure to (ζ_i) and capacity to absorb and engage in ($\theta_{i,t}$) the initiative. The outsider initially recruits local agents who are involved in the activity targeted by the development initiative. These recruits gain at levels $\gamma_{i,0} < 1$ determined by their respective network connectivities and absorptive capacities. In the next round, $t = 1$, local agents interact with contacts with whom they share common activities. Other agents will adopt the behaviour promoted insofar as their windows of influence for adoption dominate their windows of influence for non-adoption ($\omega_{i,\alpha} \geq \omega_{i,\beta}$). The gains in well-being for adoptees in round $t = 1$ will depend on the gains of all those who adopted upon recruitment of the outsider in $t = 0$ as well as their own network connectivities and capacities to learn and absorb. With each successive round, the incremental gains will become smaller as the community gains of the previous round are again filtered through the network connectivity and absorptive capacity parameters.

The structure of the model is such that transmission must proceed quickly for the initiative to meet with success. If adoption does not catch on and become widespread in short order, even those who adopted under recruitment by the outsider will find that their windows of influence for non-adoption dominate their windows for adoption, and they will revert back to non-adoption. The initiative will thus fail. This means that successful implementation of the initiative depends on the outsider reaching a critical mass of influential agents in the opening round.

7. Simulation results

To evaluate the effectiveness of the three development initiatives, we assess cumulative gains in well-being after the game has run its course and the level of adoption has reached a steady state.[13] We are interested in ascertaining which

Table 2
Initial characteristics of a diverse sample of 11 agent housholds.

i	Tier	λ	ζ	$\lambda\zeta = \theta_0$
1	*A*	0.719	0.398	0.286
3	*A*	0.594	0.427	0.254
10	*B*	0.469	0.341	0.160
12	*C*	0.344	0.370	0.127
18	*C*	0.344	0.023	0.008
25	*B*	0.469	0.351	0.165
26	*C*	0.188	0.240	0.045
29	*A*	0.438	0.509	0.223
34	*B*	0.375	0.207	0.078
47	*C*	0.406	0.404	0.164
58	*C*	0.281	0.335	0.094

Note: For each agent i, λ is wealth; ζ is network connectivity; and θ_0 is well-being at time t=0. This table is extracted from Appendix Table A1.

[13] The simulations were conducted using Netlogo (Wilensky, 1999) and UCINet (Borgatti, Everett, & Freeman, 2002).

initiative, with its particular strategy of infusion and associated channels of diffusion, is most effective in achieving welfare gains both for the community as a whole and for the lowest socio-economic tier in particular. The concrete findings will be specific to the particular network configuration of our simulation community. Careful study of the findings can nevertheless seed discussion of general principles.

For tractabilty, we present detailed results for 11 agent households of broadly representative characteristics. The initial status of these households is summarised in Table 2. The sample captures three households from the top tier of society (Tier A), three from the middle tier (Tier B), and five from the bottom tier (TierC). The least well off household in the community, with $\theta_{i=18,t=0} = 0.008$, is included as is one of the most well off households, with $\theta_{i=1,t=0} = 0.286$. Results for this sample will be indicative of broader patterns.

A simulation game begins when an outsider recruits agents and induces them to change their behaviour. The ultimate success of the initiative will depend on how effectively this opening behaviour change is propagated through the community. The windows of influence and decision results for the 11 agents of our sample are shown in Table 3 for each of the three initiatives. Under the *Education* initiative, the initial infusion occurs with recruitment of seven educators in $t = 0$. Yet as the table shows, by $t = 1$, none of the 11 agent households in the sample has adopted the behaviour change of regular school attendance promoted under the initiative ($D = 0$ for all agents). Indeed, as Table A2 for the complete set of agents shows, in the entire virtual community no member has adopted the behaviour change. An examination of values for the windows of influence for and against adoption of the new behaviour reveals why. Although contact with the converted educators is widespread, as indicated by ω_α taking on values greater than zero for all but one of the 11 agents, this is not enough to overcome the much greater influence against adoption. Some agents, for example Agent $i = 10$, actually connect with all seven of the converted educators. Even so, Agent $i = 10$ has an ω_α value for adoption of only 37 versus an ω_β value for non-adoption of 184, and hence the agent's decision is not to adopt. And so it is for the entire virtual community that $\omega_\alpha < \omega_\beta$. This applies even to the seven educator households that after their initial conversion by the outsider fall back into line with the rest of the community in declining to adopt one period later.

The outcome of the *Water* initiative, by contrast, results in success with all agents adopting the behaviour change by $t = 1$. The outsider for the *Water* initiative recruits adoptees in round $t = 0$ by going to the river bank and engaging directly with all those lacking access to tap or well water. With this approach, the outsider is able to convert 52 agents from across all three tiers (eight from Tier *A*, 19 from Tier *B*, and 25 from Tier *C*). Agent $i = 10$ is in this case among the original adoptees recruited by the outsider. The next round ($t = 1$) sees Agent $i = 10$ interact with other adoptees in sufficient numbers to confirm a window of influence for adoption ($\omega_\alpha = 204$) that dominates the window of influence for non-adoption ($\omega_\beta = 17$). Moreover, the six agents that had access to water from taps or covered wells and thus were not reached initially by the outsider (one from Tier *A*, two from Tier *B*, and three from Tier *C*), in $t = 1$ interact with others in their networks that have adopted safe water practices and decide to follow suit. This leaves the community with no agents failing to adopt the behaviour change promoted under the initiative. The initiative succeeds overall because the first round infusion generates a critical mass of influential adoptees who are able not only to bring the other members of the community into the fold but also to maintain the behaviour change among their own ranks.

The *Market* initiative, too, meets with ultimate success, although not until $t = 2$ does every member of the virtual community adopt the behaviour change. Twenty-seven agents are involved in horticultural production and wholesale trade (six from Tier *A*, 14 from Tier *B*, and seven from Tier *C*), and so are in a position to be recruited by the outsider. They then return to the community and interact with each other, as well as the remaining 31 agents, in the next period ($t = 1$). Agent $i = 10$ is again among those recruited by the outsider in $t = 0$. In $t = 1$, the behaviour to adopt is confirmed as Agent $i = 10$ faces an ω_α for adoption of 155 versus an ω_β for non-adoption of 66. There is one hold out in the community not absorbed into the initiative in $t = 1$. That is Agent $i = 18$, the least connected household in the community ($\zeta_{i=18} = 0.023$), which faced an ω_α of 10 and an ω_β of 12. However, with all other agents having decided to adopt in $t = 1$, Agent $i = 18$, too, is finally won over in $t = 2$.

Table 3
Windows of influence and decision for a sample of 11 agents under the three initiatives.

Initiative		Education			Water			Market					
Time		$t = 1$			$t = 1$			$t = 1$			$t = 2$		
i	Tier	ω_α	ω_β	D	ω_α	ω_β	D	ω_α	ω_β	D	ω_α	ω_β	D
1	*A*	15	90	0	105	0	1	90	15	1	105	0	1
3	*A*	0	105	0	90	15	1	75	30	1	105	0	1
10	*B*	37	184	0	204	17	1	155	66	1	221	0	1
12	*C*	48	289	0	313	24	1	194	143	1	337	0	1
18	*C*	3	19	0	16	6	1	10	12	0	22	0	1
25	*B*	40	196	0	219	17	1	169	67	1	236	0	1
26	*C*	22	187	0	199	10	1	116	93	1	209	0	1
29	*A*	15	117	0	117	15	1	93	39	1	132	0	1
34	*B*	25	113	0	127	11	1	99	39	1	138	0	1
47	*C*	53	310	0	337	26	1	218	145	1	363	0	1
58	*C*	49	256	0	279	26	1	175	130	1	304	1	1

Note: For each agent i, ω_α is the window of influence for adoption of a behaviour change, ω_β the window for non-adoption; and D is the adoption decision with $D = 1$ indicating adoption, $D = 0$ non-adoption. This table is extracted from Appendix Table A2.

Table 4
Impact on well-being: *Education* Initiative.

i	Tier	$t=0$		$t=1$	
		$\sum_{j_\infty} x_{j_\infty,n}$	γ	θ	$\Delta\theta_T$ (%)
1	*A*	0	0.000	0.286	0.0
3	*A*	1	0.108	0.362	42.5
10	*B*	0	0.000	0.160	0.0
12	*C*	0	0.000	0.127	0.0
18	*C*	0	0.000	0.008	0.0
25	*B*	1	0.058	0.222	34.5
26	*C*	0	0.000	0.045	0.0
29	*A*	0	0.000	0.223	0.0
34	*B*	0	0.000	0.078	0.0
47	*C*	1	0.066	0.230	40.2
58	*C*	0	0.000	0.094	0.0

Note: For all agents i, $\Sigma x_{j,n}$ is the number of connections with all other agents j participating in shared activity n; γ is the increase in well-being in time t associated with adopting and realizing by degree a change in behaviour; θ is the level of well-being in time t; and $\Delta\theta_T$ is the rate of increase in aggregate well-being in $t=T$ relative to $t=0$.

Table 5
Impact on well-being: *Water* Initiative.

i	Tier	$t=0$		$t=1$			$t=2$	
		$\sum_{j_\infty} x_{j_\infty,n}$	γ	θ	$\sum_{j_\infty} x_{j_\infty,n}$	γ	θ	$\Delta\theta_T$ (%)
1	*A*	0	0.000	0.286	190	0.008	0.293	2.4
3	*A*	1	0.108	0.362	202	0.010	0.372	46.5
10	*B*	1	0.055	0.214	164	0.005	0.219	36.9
12	*C*	1	0.047	0.174	179	0.004	0.179	40.9
18	*C*	0	0.000	0.008	9	0.000	0.008	0.0
25	*B*	1	0.058	0.222	169	0.005	0.227	37.6
26	*C*	1	0.011	0.056	119	0.001	0.057	26.7
29	*A*	1	0.113	0.336	245	0.011	0.347	55.6
34	*B*	0	0.000	0.078	96	0.001	0.079	1.3
47	*C*	1	0.066	0.230	194	0.006	0.236	43.9
58	*C*	1	0.032	0.126	159	0.003	0.129	37.2

See note for Table 4.1

The effect on an agent's well-being of adopting a change in behaviour depends on how thoroughly the agent understands and commits to the new behaviour. The degree of realization of a behaviour change for any one agent depends on the overall realization of the change in the community. Tables 4–6 detail the gains in well-being for the 11 agents of our sample under the three initiatives. The cumulative gain in well-being is expressed proportionally as $\Delta\theta_T = (\theta_T - \theta_0)/\theta_0$.

Under the *Education* initiative, shown in Table 4, three of the 11 agents are recruited by the outsider at $t=0$. Each of the adopting agents benefits from a gain in well-being that is some fraction of the fully realized gain of the outsider, $\gamma_{j_0} = 1$, where that fraction depends on the agent's individual capacity to learn and implement the behaviour as expressed in Eq. (6). The three recruited educator households enjoy substantial gains in well-being on the order of 35–43%. Yet their numbers and standing in the community are not such as to propogate the behaviour change and bring about success of the initiative. Hence no one else in the community benefits.

Under the *Water* initiative, as shown in Table 5, eight of the 11 agents in the sample are recruited by the outsider in $t=0$, with all 11 adopting the behaviour change in $t=1$. The incremental gains in welfare in t=1 are seen to be much lower than those in $t=0$. That is because opening round adopters learn the new behaviour directly from the outsider who possesses full knowledge of and dedication to it. By $t=1$, the outsider is gone and the understanding and commitment to the new behaviour have become diluted as it spreads through the community. Cumulative welfare gains for the 11 agents range from negligible to 55.6%. Although Agent $i=18$ adopts the change in behaviour in $t=1$, this agent's active realization of the change is poor due to its paucity of connections and limited capacity to absorb new things. At the opposite extreme, the well connected and high functioning Agent $i=29$ enjoys a 56% gain in well-being.

Under the *Market* initiative, shown in Table 6, four of the 11 sample households benefit from the strong gains in welfare associated with recruitment by the outsider. With each successive round of the game, the incremental gains become more diluted. This suggests a substantial premium to early joining so as to benefit from proximity to the outsider and the high information content and capability for implementation that entails. Cumulative welfare gains range from negligible even with adoption of the new behaviour to 57.0%.

Table 6
Impact on well-being: *Market* Initiative.

i	Tier	$t=0$		$t=1$			$t=2$			$t=3$	
		$\sum_{j_x} x_{j_x,n}$	γ	θ	$\sum_{j_x} x_{j_x,n}$	γ	θ	$\sum_{j_x} x_{j_x,n}$	γ	θ	$\Delta\theta_T$ (%)
1	*A*	0	0.000	0.286	101	0.009	0.294	203	0.001	0.295	3.1
3	*A*	1	0.108	0.362	105	0.011	0.373	218	0.001	0.374	47.2
10	*B*	1	0.055	0.214	86	0.005	0.220	175	0.000	0.220	37.5
12	*C*	0	0.000	0.127	92	0.004	0.131	190	0.000	0.131	3.1
18	*C*	0	0.000	0.008	5	0.000	0.008	12	0.000	0.008	0.0
25	*B*	1	0.058	0.222	92	0.006	0.228	180	0.000	0.229	38.8
26	*C*	0	0.000	0.045	57	0.001	0.046	123	0.000	0.046	2.2
29	*A*	1	0.113	0.336	122	0.013	0.349	261	0.001	0.350	57.0
34	*B*	0	0.000	0.077	56	0.001	0.079	105	0.000	0.079	1.3
47	*C*	0	0.000	0.164	106	0.005	0.169	207	0.000	0.169	3.0
58	*C*	0	0.000	0.094	85	0.002	0.097	171	0.000	0.097	3.2

See note for Table 4.1 .

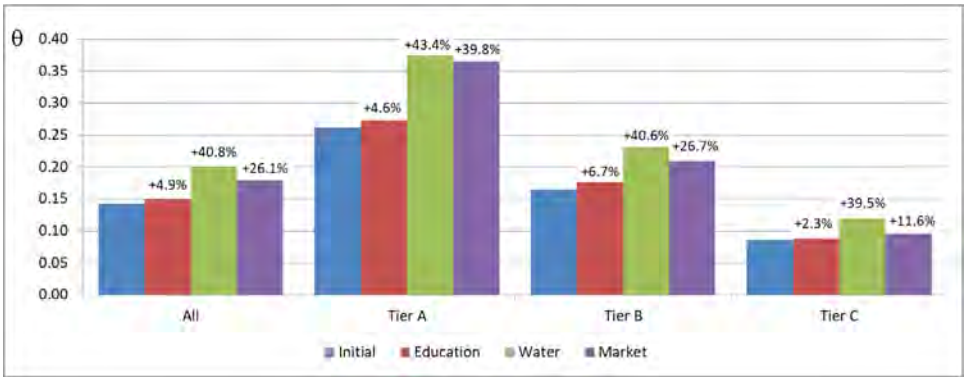

Fig. 2. Changes in welfare by initiative and socio-economic tier.

Fig. 2 presents welfare gains in the aggregate by initiative and socio-economic tier. The greatest gains for the community as a whole as well as for each socio-economic tier are achieved under the *Water* initiative. This is because the simulation model attaches a substantial premium to learning a new behaviour directly from the outsider who spearheads the initiative, and under the *Water* initiative the outsider comes into direct contact with the greatest number of community members. The *Education* initiative, because it reaches few community members initially and ultimately fails, yields the lowest welfare gains.

The *Water* initiative further stands out for achieving gains for Tier *C* households that, in percentage terms, are nearly as great, at 39.5%, as those received by Tier *A* and Tier *B* households, at 43.4% and 40.6% respectively. This is because the outsider is effective in directly reaching households from Tier C by going to the riverbank where they collect water. Even though by design of the model Tier *C* households have lower capacity to effectively realize changes in behaviour, direct contact with the outsider to a large extent overcomes this deficiency. By contrast, the *Market* initiative confers much greater gains on Tier *A* (39.8%) than on Tier *B* households (26.7%), and in turn much greater gains on Tier *B* than Tier *C* households (11.6%). This is because the *Market* initiative reaches first those who are already relatively well off through their involvement in commercial farming. The *Education* initiative has its greatest impact on Tier *B* households because this is the tier that includes the largest proportion of educator households. But even in this tier, the proportion of educator households is too small to have an appreciable impact overall.

8. Discussion and implications for policy

We put forward an agent based model that is inductive in approach, basing our agent households on actual members of a rural southern Lao community. We build a networked society from the bottom up based on activities shared among households. The appeal of agent based modeling is that it does away with unrealistic assumptions of agent homogeneity and generic environments for individual choice. The model was used to examine the implementation of three development initiatives intended to improve well-being for the rural poor. The initiatives begin with contact to select households by an outsider who seeks to induce a change in behaviour. The simulation exercise then tracks the transmission of this behaviour

change through the community to a steady state outcome wherein all households have either adopted or declined to adopt the new behaviour.

The *Education* initiative works through teachers and school administrators to encourage school attendance. The *Water* initiative reaches out to those gathering water at the river to promote boiling of water and use of safe containers. The *Market* initiative works through those who grow commercial crops to encourage broader engagement in market based trade.

The simulation exercise shows the *Water* initiative to be most successful both for the community as a whole and in reaching the lowest tier of society. The key to this success is initial contact by the outsider that is broad based and effectively targeted to the poor. By contrast, the *Education* initiative fails to transmit a behaviour change, such that ultimately even the educators give up. The initiative does not gain traction because the opening foray does not reach a critical mass of well-networked and influential community members. Finally, the *Market* initiative succeeds in reaching all community members, but the gains accrue disproportionately to the well-off who are best positioned to absorb the initial impetus.

The simulation exercise is, of course, a highly stylized representation of the transmission of development initiatives through a community. Nevertheless, it does serve to explain salient observations with respect to the three initiatives actually implemented in our rural Lao community. These observations are: 1) that half the schools were empty when we visited and children were found fishing at the river or catching snakes or rodents in the rice fields; 2) that even the poorest of families boiled their water before drinking, and told us that 'it's good for the children's health'; and 3) that the young women of the community were hard to find during the early part of the day because they 'went with their friends' and were later seen to have returned bearing household items or foodstuffs purchased on the market with proceeds from selling vegetables. We tracked results systematically by asking: "Are the children attending school?" "Are you boiling water?" "Do you understand why you should not use rusty buckets?" "Is anyone in the household going to the district market or Pakse?" Answers were positive with respect to the water and market behaviour, but not with respect to school attendance.

The model offers insight into the failure of the *Education* initiative. In our real society, we observed that most people rejected the 'education for all' campaign as shown by the lack of attendance at school. We infer that the majority of villagers perceive school education as having little relevance to their current economic situation. The fact that the campaign touched no one in the community other than those educators who were first recruited was a bad sign. These educators are not necessarily well connected in the neighbourhood, and such lack of connectivity curtailed the spread of benefits to others. It might be assumed a priori that reliance on educators in a development campaign would be effective given their status and the weight accorded their advice in the community. However, it appears that the approach of the *Education* campaign was too narrow and exclusive for it to catch on broadly.

With regard to market engagement, in the actual Lao community awareness of the potential for such activity spread as farmers watched their neighbors take advantage of the opportunity presented by a new feeder road. This led the onlookers, too, to change their behaviour once they realized the benefits are possible for them as well. In concrete terms, we witnessed vegetable growing households send a member to the market to sell their produce once the feeder road provided vehicular access. To serve households that did not own a motor vehicle, commercial transport service developed involving pick-up trucks adapted to seat passengers (known as songthaew). This pursuit of market opportunities was a direct consequence of strong social networks that facilitated the spread of a new way of life through the community.

The agent based simulation exercise nevertheless has its limitations. Whether the education campaign failed due to an ill-conceived infusion strategy given the network characteristics of the community or for other reasons is an open question. Perhaps the costs of sending children to school were regarded as too high by the villagers relative to perceived benefits. Rather than going to school, children could be contributing to the household with immediate, tangible return. Given an unfavorable perception of costs and benefits, if the *Education* campaign instead of being introduced via teachers had been promoted to household members at the river bank in the manner of the *Water* initiative, would it have succeeded or would households still have been unreceptive? This is beyond the scope of the simple model of this paper to assess.

This paper introduces a quantitative method of evaluating the effectiveness of development strategies at their core – the process of diffusion. The emphasis is on mapping the locus of infusion and tracing the process by which an initiative then diffuses through a community. This supplements the more standard evaluative focus on outcomes using methods that may obscure impediments to an initiative's achieving broad based success or inequities in its reach. It is important to understand the paths by which ideas or practices or new technologies diffuse through a society, as important as it is to measure the final outcome. A methodology for adding such texture to the analysis could help to illuminate why a program works better in one community than another or how to best reach those in the lowest strata of society.

Two aspects of the agent based modeling approach are worth emphasizing. One is its attention to the characteristics of a particular community. Seemingly viable, well intentioned, and previously successful development programs may well fail because the manner in which they are delivered is not suited to the particular socio-economic dynamics of a community. Such preconditions are an issue in any environment, but may be especially important within developing economies where custom and power structure may prevail over market price signals and the intentions of the aid giver. Social attributes (status, gender, and the like) and political structures (clan and village structures, local government) can create unexpected barriers to financial aid and the diffusion of economic improvements. Such local preconditions may explain much of the divergent and often disappointing performance of standard aid packages. Understanding the nature of such preconditions could be the key to moving beyond superficial assessments of program achievements and elaborating how the program has served certain groups or individuals.

The second aspect of agent based modeling deserving of emphasis is its incorporation of learning through word of mouth as the mechanism for achieving changes in behaviour. Word of mouth is an essential form of communication in areas where education is poor and literacy rates are low. But information degrades through word of mouth. Detail is lost and the potency of the message is weakened with each successive round of interaction as one individual speaks to another who then speaks to yet another. It is crucial, therefore, that knowledge be inculcated through diverse channels of interaction and with repetition. This is true especially when targeting the poor. The model thus treats as foundational the recruitment phase or infusion point of the campaign, and puts the social network in position to take over from there.

The model could be improved with more elaborate characterization of the value of endowments and the quality of network connections. This would require more careful data collection at the household survey stage. The survey data collected for the exercises of this paper were incomplete and inconsistent with observed realities. A more ambitious improvement would be to account at the household level for the costs and benefits of making a behaviour change. This would require information on household income and expenditures to frame the decision making process. At a more overarching level, we would want also to consider the cost of the campaign itself. In the simple modeling exercise of this paper, we have implicitly assumed that for the household, the benefit of a behaviour change outweighs the cost so that the choice rests entirely on gaining an understanding of this fact.

In its simple form, our approach serves as a complement to more standard methods of project evaluation. Agent based modeling provides a framework for constructing a virtual society akin to one that actually exists and for then simulating the process by which a development initiative either does or does not take hold. The framework yields insight into the effectiveness of alternative strategies for infusing knowledge into a community with the intent of catalyzing behaviour change. Whereas other methods of project evaluation are aimed simply at ascertaining whether a project succeeded or failed, agent based modeling is designed to understand why.

Acknowledgements

The author wishes to sincerely thank the reviewers for providing insightful comments and valuable suggestions on the draft of this paper, and for the commendable thoroughness of their review, showing immense knowledge of the real issues facing developing communities.

Appendix A.

See

Table A1
Household indicators of wealth, network connectedness, and well-being.

i	Tier	λ_i	ζ_i	θ_i
1	*A*	0.719	0.398	0.286
2	*A*	0.625	0.267	0.167
3	*A*	0.594	0.427	0.254
4	*B*	0.438	0.306	0.134
5	*B*	0.625	0.302	0.189
6	*B*	0.469	0.505	0.237
7	*A*	0.562	0.304	0.171
8	*B*	0.375	0.417	0.156
9	*A*	0.625	0.462	0.289
10	*B*	0.469	0.341	0.160
11	*B*	0.469	0.388	0.182
12	*C*	0.344	0.370	0.127
13	*B*	0.438	0.322	0.141
14	*A*	0.625	0.462	0.289
15	*B*	0.469	0.380	0.178
16	*B*	0.438	0.230	0.101
17	*A*	0.625	0.491	0.307
18	*C*	0.344	0.023	0.008
19	*C*	0.281	0.283	0.080
20	*B*	0.312	0.283	0.088
21	*B*	0.312	0.341	0.107
22	*B*	0.406	0.341	0.139
23	*B*	0.406	0.312	0.127
24	*B*	0.406	0.364	0.148
25	*B*	0.469	0.351	0.164
26	*C*	0.188	0.240	0.045
27	*C*	0.094	0.331	0.031
28	*A*	0.750	0.491	0.368
29	*A*	0.438	0.509	0.223

Table A1 (*Continued*)

i	Tier	λ_i	ζ_i	θ_i
30	*C*	0.312	0.394	0.123
31	*C*	0.156	0.423	0.066
32	*C*	0.125	0.331	0.041
33	*C*	0.094	0.296	0.028
34	*B*	0.375	0.207	0.078
35	*C*	0.406	0.183	0.074
36	*C*	0.156	0.331	0.052
37	*C*	0.188	0.437	0.082
38	*B*	0.469	0.452	0.212
39	*C*	0.219	0.423	0.092
40	*C*	0.188	0.411	0.077
41	*C*	0.312	0.378	0.118
42	*C*	0.281	0.382	0.108
43	*C*	0.312	0.382	0.119
44	*B*	0.469	0.402	0.188
45	*C*	0.312	0.207	0.065
46	*B*	0.562	0.470	0.264
47	*C*	0.406	0.404	0.164
48	*B*	0.469	0.483	0.227
49	*C*	0.188	0.296	0.056
50	*C*	0.281	0.491	0.138
51	*C*	0.219	0.302	0.066
52	*C*	0.281	0.378	0.106
53	*C*	0.219	0.470	0.103
54	*B*	0.531	0.476	0.253
55	*C*	0.281	0.361	0.101
56	*C*	0.344	0.462	0.159
57	*C*	0.219	0.361	0.079
58	*C*	0.281	0.335	0.094
58	*C*	0.281	0.335	0.094

For each agent *i*, λ_i is wealth; ζ_i is network connectivity; and θ_i is well-being.

Table A2
Windows of influence and decision by initiative

Initiative		Education			Water			Market					
Time		*t*=1			*t*=1			*t*=1			*t*=2		
i	Tier	ω_α	ω_β	*D*	ω_α	ω_β	*D*	ω_α	ω_β	D_1	ω_α	ω_β	*D*
1	*A*	15	90	0	105	0	1	90	15	1	105	0	1
2	*A*	6	63	0	63	6	1	54	15	1	69	0	1
3	*A*	0	105	0	90	15	1	75	30	1	105	0	1
4	*B*	38	160	0	181	17	1	137	61	1	198	0	1
5	*B*	31	177	0	191	17	1	134	74	1	208	0	1
6	*B*	57	274	0	299	32	1	236	95	1	331	0	1
7	*A*	9	66	0	66	9	1	57	18	1	75	0	1
8	*B*	53	222	0	248	27	1	184	91	1	275	0	1
9	*A*	15	105	0	105	15	1	87	33	1	120	0	1
10	*B*	37	184	0	204	17	1	155	66	1	221	0	1
11	*B*	43	199	0	220	22	1	163	79	1	242	0	1
12	*C*	48	289	0	313	24	1	194	143	1	337	0	1
13	*B*	40	179	0	202	17	1	158	61	1	219	0	1
14	*A*	15	105	0	105	15	1	87	33	1	120	0	1
15	*B*	40	218	0	236	22	1	183	75	1	258	0	1
16	*B*	31	123	0	144	10	1	116	38	1	154	0	1
17	*A*	15	111	0	111	15	1	93	33	1	126	0	1
18	*C*	3	19	0	16	6	1	10	12	0	22	0	1
19	*C*	38	213	0	235	16	1	151	100	1	251	0	1
20	*B*	35	147	0	170	12	1	130	52	1	182	0	1
21	*B*	37	184	0	204	17	1	155	66	1	221	0	1
22	*B*	37	184	0	204	17	1	155	66	1	221	0	1
23	*B*	34	172	0	189	17	1	148	58	1	206	0	1
24	*B*	40	186	0	209	17	1	156	70	1	226	0	1
25	*B*	40	196	0	219	17	1	169	67	1	236	0	1
26	*C*	22	187	0	199	10	1	116	93	1	209	0	1
27	*C*	34	255	0	272	17	1	169	120	1	289	0	1
28	*A*	15	111	0	111	15	1	93	33	1	126	0	1

Table A2 (*Continued*)

Initiative		Education			Water			Market					
Time		*t*=1			*t*=1			*t*=1			*t*=2		
i	Tier	ω_α	ω_β	*D*	ω_α	ω_β	*D*	ω_α	ω_β	D_1	ω_α	ω_β	*D*
29	*A*	15	117	0	117	15	1	93	39	1	132	0	1
30	*C*	46	300	0	325	21	1	204	142	1	346	0	1
31	*C*	46	328	0	348	26	1	217	157	1	374	0	1
32	*C*	34	260	0	275	19	1	164	130	1	294	0	1
33	*C*	35	222	0	238	19	1	146	111	1	256	1	1
34	*B*	25	113	0	127	11	1	99	39	1	138	0	1
35	*C*	24	141	0	151	14	1	101	64	1	165	0	1
36	*C*	34	255	0	272	17	1	169	120	1	289	0	1
37	*C*	46	343	0	358	31	1	220	169	1	389	0	1
38	*B*	44	238	0	260	22	1	192	90	1	282	0	1
39	*C*	46	328	0	348	26	1	217	157	1	374	0	1
40	*C*	46	317	0	340	23	1	209	154	1	363	0	1
41	*C*	44	291	0	309	26	1	186	149	1	335	0	1
42	*C*	44	293	0	314	23	1	188	149	1	337	0	1
43	*C*	44	293	0	314	23	1	193	144	1	337	0	1
44	*B*	43	211	0	227	27	1	175	79	1	254	0	1
45	*C*	27	160	0	167	20	1	111	76	1	186	1	1
46	*B*	44	249	0	269	24	1	207	86	1	293	0	1
47	*C*	53	310	0	337	26	1	218	145	1	363	0	1
48	*B*	58	257	0	286	29	1	216	99	1	315	0	1
49	*C*	35	222	0	238	19	1	150	107	1	256	1	1
50	*C*	62	381	0	412	31	1	263	180	1	443	0	1
51	*C*	34	227	0	249	12	1	152	109	1	261	0	1
52	*C*	36	296	0	313	19	1	190	142	1	332	0	1
53	*C*	48	369	0	389	28	1	231	186	1	417	0	1
54	*B*	47	251	0	271	27	1	213	85	1	298	0	1
55	*C*	36	284	0	301	19	1	180	140	1	320	0	1
56	*C*	60	357	0	386	31	1	247	170	1	417	0	1
57	*C*	36	279	0	298	17	1	180	135	1	315	0	1
58	*C*	49	256	0	279	26	1	175	130	1	304	1	1

Note: For each agent *i*, ω_α is the window of influence for adoption of a behaviour change, ω_β the window for non-adoption; and *D* is the adoption decision with $D = 1$ indicating adoption, $D = 0$ non-adoption.

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