

The Impact of HIV/AIDS in the Context of Socioeconomic Stressors: an Evidence-Driven Approach

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Abstract

In this paper, we present an agent-based simulation model of the social impacts of HIV/AIDS in villages in the Sekhukhune district of the Limpopo province in South Africa. AIDS is a major concern in South Africa, not just in terms of disease spread but also in term of its impact on society and economic development. The impact of the disease cannot however be considered in isolation from other stresses, such as food insecurity, high climate variability, market fluctuations and variations in support from government and non-government sources. The model described in this paper focuses on decisions made at the individual and household level, based upon evidence from detailed case studies, and the different types of networks between these players that influence their decision making. Key to the model is that these networks are dynamic and co-evolving, something that has rarely been considered in social network analysis. The results presented here demonstrate how this type of simulation can aid better understanding of this complex interplay of issues. In turn, we hope that this will prove to be a powerful tool for policy development.

Keywords:

Agent-Based Social Simulation, Evidence-Driven Modeling, Socioeconomic Stressors, HIV/AIDS Impact

Introduction

1.1

Evidence-driven agent based modelling constrains agent and mechanism design by independent evidence about the behaviour of the actors represented by the agents. This approach has been a niche activity in the social simulation research. In the year to May 2007, only a single paper ([Xiong and Ma 2007](#)) in which agent behaviour was built on descriptions of specific and identifiable actors has been published in this journal. And the number published in the whole nearly eleven-year history of JASSS is certainly less than ten. JASSS' sister journal, *Computational and Mathematical Organization Theory* has not reported a single evidence-driven agent based model in at least the past four years.

1.2

Experience and knowledge of the social simulation community indicates that the scant presence of evidence-driven agent based models in the leading journals in the field is a fair reflection of the balance of social simulation research. We also note that to produce such models requires the modellers to engage deeply with the evidence and frequently to go back to expert informants as issues are identified in the course of the modelling process. This is a much more time consuming process than the implementation of models driven by prior theoretical considerations or developed *ad hoc* on the basis of introspection and/or speculation. Consequently, the rate of production of models (and therefore articles) produced per author is necessarily smaller than the rate of production of theoretical or methodological papers. We would expect there to be fewer evidence driven papers submitted to the journals.

1.3

The question this raises is whether the greater effort is matched by greater gain. The direct beneficiaries of such evidence driven modelling are the relevant stakeholders.

1.4

The pioneers in this niche, Barreteau and Bousquet (e.g., [1999](#)), have used role play and similar knowledge elicitation techniques to inform models at village and similar scale. Barthelemy ([2006](#)), building on Downing *et al.* ([2000](#)), produced a reasonably elaborate model of domestic water demand for a large area of southern England (including London) based on information from water supply companies and their regulators but without the rich detail obtained by Barreteau, Bousquet and their colleagues.

1.5

Barreteau and Bousquet produced their models to inform decision making by the villagers they were modelling. Moss' ([1998](#)) model of critical incident management did inform the development of emergency procedures in a major utility company. However, the models of Barthelemy and colleagues in the Centre for Policy Modelling (CPM) implied the inapplicability of prevailing analytical techniques used by water supply companies and these results were simply not welcome. There is evidently a political dimension to the usefulness of these model-based analyses for stakeholders.

1.6

For the social scientists, there may be a more generic benefit. Developers of evidence driven models may well find that many of them produce results with common attributes. If these common attributes turn out to be general consequences of observed individual and social behaviour, they could constitute or inform the search for general social theory.

1.7

The present article builds on both of the Barreteau-Bousquet and the CPM traditions in evidence-driven agent based modelling. Agent behaviour and social interaction were designed to reflect expert evidence obtained over a decade or so of intensive field work by several research teams. Where evidence was lacking but some element of behaviour or epidemiology had to be specified, we have had to make assumptions. These were discussed with our domain experts but have also been documented and are the subject of further, ongoing field research.

1.8

This paper is focused on the issue of how HIV/AIDS influences the livelihoods and the household structure of a rural community in South Africa. We do this by presenting an evidence-based model of the interplay of social processes and the effects of the resulting networks of individuals and households in the community. This model, developed using data from field work surveys and interviews in the Limpopo province in South Africa, demonstrates how a social simulation model can be helpful in understanding the impact of policy change.

1.9

Research into the socioeconomic impact of HIV/AIDS has become a top priority of the United Nations and other nongovernmental organizations (NGOs) over the last few years ([Kalipeni et al. 2004](#)). In South Africa the epidemic has increased from a prevalence of less than 1% among adults to almost 25% within ten years ([UNAIDS 2005](#)). A recent study shows that from 1997 to 2002 the death rate increased by 62%^[1]. However, the impact of HIV/AIDS cannot be measured in terms of the death rate alone: one of the major concerns is that the nature of the disease means that those most likely to be infected are the young sexually-active adults. This means that communities become skewed, with relatively large numbers of children and elderly, and relatively few fit, strong and productive members. It is therefore necessary to investigate this impact of HIV/AIDS at the communal level ([Foster 2005](#); [Poku and Whiteside 2004](#)).

1.10

Agent-based social simulation ([Gilbert and Troitzsch 2005](#)) is a tool well suited for an investigation of this sort since it allows for the necessary detail in

modelling the effects of stressors such as HIV/AIDS on social networks. Unlike conventional epidemiological models that operate on the level of whole populations and therefore concentrate on 'average' behaviour, agent-based models can take the actual behaviours of individuals into account. This is a prerequisite for investigating impacts on social networks and communities. Over the last few years, this has been recognized by the life science community concerned with modelling the HIV/AIDS epidemic. However, even though HIV/AIDS is a key concern, its impact in South Africa cannot be examined in isolation of other stressors, such as food insecurity, high climate variability, market fluctuations, and poor governance ([Ziervogel et al. 2005](#)).

1.11

In this paper, we present a model that captures socioeconomic stressors experienced by the villagers in the Sekhukhune district, Limpopo Province, South Africa. The model has been driven by evidence made available, primarily, from our case study team at the Stockholm Environment Institute (Oxford) as well as secondary sources. The nature of this evidence is both quantitative and qualitative (based on the verbal accounts from stakeholders as well as semi-structured interviews). Moss and Edmonds ([2005a](#); [2005b](#)) have argued for models developed bottom-up, where the available evidence is not ignored for simplicity's sake. We believe a model's purpose in social simulation is to enhance, if possible, our understanding of the underlying problem. It can be helpful to the policy-makers and stakeholders in designing better policies when the representation of the social processes in the model is accessible to them. Our model is descriptive in nature and is an example of the KIDS (keep it descriptive, stupid) modelling principle ([Edmonds and Moss 2005](#)). We have relied on a number of assumptions as well, like any other model, when direct evidence is not available. Where such assumptions have been made, the choices have been discussed with our case study team and are also subject to validation through ongoing fieldwork.

1.12

The rest of the paper is structured as follows: Section 2 discusses the case study region. It focuses on the endogenous and exogenous socioeconomic drivers that affect people's lives. Section 3 describes the model we have developed while section 4 reports the dynamic behaviour of the model. This is followed by a selection of specific scenarios in section 5, followed by discussion. Finally, conclusions drawn from our work so far and future perspectives are presented.

The Case Study

2.1

The case study for this work focuses on Sekhukhune district that until 2006 was a cross-border district occupying the northern part of Mpumalanga and the southern part of Limpopo Province, but now lies entirely in Limpopo Province. The area is arid, with few urban centres, located approximately 200km northeast of Pretoria. In the case study area, there are a range of stressors to which people are exposed, including water scarcity, climate variability, HIV/AIDS and food insecurity, that lead to high vulnerability ([Ziervogel et al. 2005](#); [2006a](#); [2006b](#)). The population in the case study area is highly reliant on state grants such as pensions or child/orphan grants, as well as money sent home from family members who have migrated to other areas for work. Although this is a predominantly rural area, agriculture alone is insufficient for the population's food needs. In fact, recent reports show that most people have stopped taking part in agriculture at all because problems with water supply can mean that the cost of growing crops is greater than the return. Death of a family member receiving a grant or sending money home can therefore have a devastating effect on a household.

2.2

The nature of HIV/AIDS means that the population has a high number of orphan children. Households typically consist of more than just a typical nuclear family, but nevertheless there are times at which a household is left with no adult members. In such situations, orphan children are usually accommodated by a household within the extended family.

2.3

With regards to social policy and its applications, the above-mentioned issues need to be tackled both at the national and the district levels. The former concerns the implications for food and basic amenity subsidies for the local districts, whereas authorities at the district level are often interested in the distribution of available resources to the villages and efforts towards sustainability of households. Many of the social networks in this area operate at the household level rather than the individual level, and pooling of finances, mutual help and resource-sharing among members are the basis of these networks. Such networks are dynamic in the sense that existing households in the community disintegrate and new ones are created. Consequently, relationships among the members of the networks change over time. The dynamics of the social networks result from the interplay of both exogenous and endogenous processes mentioned above.

2.6

A key stress in the area is water scarcity that constrains not only field-based agriculture, livestock, home gardens and domestic chores but also development projects such as brick-making etc. A large dam, De Hoop, has been planned in the region, and construction is expected to start this year, yet there are environmental concerns about it. Another key stress in the area is unemployment. Over 90% of the population lives in rural areas and there are very few jobs in the villages ([Ziervogel et al. 2006b](#)). People therefore tend to migrate to urban areas to find employment. This is often regulated by social networks, as people migrate to areas where they have friends or family with whom they can stay while they are looking for work. Mines in the region also provide employment opportunities, although they have associated costs. Many of the jobs at the mines require particular skills which are not available in the local population. This means that there is a consequent inward migration to the region, and associated with this is a concern that there is an increased risk of HIV/AIDS spread.

2.7

Much of the data used to develop this model have been supplied by our fieldwork team on the CAVES project^[2]. They have been involved in a series of surveys and interviews with residents in the region over a number of years, and a series of model versions have been developed iteratively based on the feedback from our domain experts. Additional data were provided by RADAR^[3], an organization working in the same region. Through their work, the RADAR team has acquired extensive data concerning household compositions, people's affiliation to various organizations and safety-net schemes, and data related to individual and household-level characteristics. We have also made use of the existing literature and external references. The next section discusses the way in which we have used these data to construct our model, as well as further details of the context of our case study.

Model Specification

3.1

The agents in our model represent individuals in the case study. Networks within the model emerge both at the individual level and at the household level, where a household is a group of individual agents in which a single agent typically takes responsibility for decisions at this level. The model thus takes into account both the individual interactions and the dynamics between households. It has been implemented in Java, making use of both the Repast^[4] toolkit and Jess^[5]. Pajek^[6] has also been used to visualize the emerging networks. Time in the model progresses in monthly steps and typical scenarios extend over many years. The source code is available on request from the first author.

Individual agents

3.2

Agents in the model represent individuals who are characterized by their gender, age group, marital status, health status and expected normal age. Agents are created at the start of the simulation run, and further agents are born during the run of the simulation. The agents age as the simulation proceeds and become involved in the social processes individually as well as collectively. Table 1 illustrates the basic attributes of an agent in the model.

Table 1: Agent's characteristics

Attribute	Possible values
Gender	Female; male
Age Group	Child [0–16); adult [16–45); senior [45–onwards) years
Health Status	Well/ok; HIV/AIDS; old-age sickness; disabled

Life Expectancy Sampled from Normal Distribution with values of mean expected age (56 years) and standard deviation (10 years), as abstracted from the demographic data.

Hunger Status Fully-fed; half-fed; not-fed

HIV/AIDS spread

3.5

One of the key individual-based processes in our model is the spread of HIV/AIDS. One way of modelling this spread would be to model the sexual activities of agents, however this is both a socially and politically sensitive topic for which it would be difficult to gather data (and may indeed interfere with the trust that has been established between fieldwork team and the subjects of the case study). Several epidemiological models have addressed the issue of modelling the HIV/AIDS spread in sub-Saharan Africa including agent-based models, for example, ([Alam et al. 2006](#); [Heuveline et al. 2003](#); [Handcock et al. 2003](#); [Teweldemedhin et al. 2004](#)). However as the spread of HIV/AIDS is not itself the focus of our work, we have adopted the distribution-based approach of Salomon et al. (2000), using the 'Gamma' distribution as it was closest to the demography of our case study region. The proportion of 'new HIV/AIDS adult patients at each year are calculated as follows:

$$\text{HIV/AIDS Incidence (t: year)} \leftarrow \text{Gamma}(\alpha, \beta)$$

where the distribution parameter values for α and β used in the reported simulation runs are 12 and 1.25 respectively. The values are taken from Salomon et al. (2000) based on their study in the region.

3.8

The effect of migration is significant in the transmission of HIV/AIDS. We know from the fieldwork research that migrant workers visit their spouses every two or three months at the least. As the incidence data are used at an annual time scale in the model, an implicit assumption is that if an agent contracts HIV/AIDS, their spouse also becomes infected. Furthermore, around 20–45% of the children born of HIV-positive mothers are infected with HIV as well^[7]. We have used 30% in our simulations for the probability of a mother to child transmission. We have also assumed that there are no antiretroviral drugs accessible to the villagers. Although such drugs have been reported to have reduced the risk of HIV to as low as 2%, which obviously has both short and long-term implications, they have not yet been available in our case study region.

Agent's health status

3.9

In this model we measure the agent's health as a proportion of full fitness, as is done in several other models such as those of Werth and Moss (2007) and Younger (2005). In reality it is difficult to ascribe a concrete number to an individual's health (such as "X is 56% fit"), and we are aiming for a qualitative rather than quantitative measure of health. At this stage of our work we do not have sufficient data on how exactly this would be modelled however, and are relying on the outcomes of further fieldwork for this refinement.

3.10

Modelling an agent's food and nutritional requirement is important especially as food insecurity and declining health are seen as prime stressors by the stakeholders ([du Toit and Ziervogel 2004](#); [Mahloele 2005](#)). In our case, we have introduced a more focused representation of an agent's food requirement. This is implemented by using Adult-Health Equivalent estimates^[8], whereby health declines when food needs are not met. Another significant impact on an agent's health status is the incidence of HIV/AIDS: a patient's health decreases more rapidly after the incubation period. As UNAIDS reports ([UNAIDS 2006](#)), the median time from HIV/AIDS infection to death is 8–9 years and this is reflected in our model. To model the decay in health of an infected individual, the Sigmoid (S-) function is used. We consider an incubation period of 18 months on average and a median time of 8–9 years from infection to death.

Agents' births during simulation

3.11

In the model, children are born to married couples. A birth is possible if both partners are alive, at least one year has passed since the mother last gave birth, and the mother is 'well.' The mother is considered to be able to give birth until 8 years (or 96 months) after HIV/AIDS infection. If a birth is possible according to these rules, it occurs with a fixed chance, set to 30% in our model ([Heuveline 2004](#)).

Ability to work

3.12

Healthy agents are expected to look for village employment and part-time jobs. However the availability of such work is limited and so not all able agents receive work. In our model, 40–50% male and 30–40% female agents receive income in this way, and the remittances are sampled (see appendix 'A' for the values used). The proportion of working agents and the value of their income are both assumed from anecdotal accounts—further data gathering is required for more concrete values.

3.13

The model selects 40–50% male and 30–40% female agents who get involved in village-based labour. This proportion is in accordance with the anecdotal accounts. The money earned is calculated as follows:

$$\text{Village-labour-income} \leftarrow \text{Normal}(100, 25)$$

The values have been found plausible from the anecdotal accounts only. Use of the normal distribution is an otherwise unvalidated model's assumption.

Households Representation

3.14

In the region in which our case study is based, the notion of a 'household' is not well-defined. Unlike the typical understanding of a household being either a nuclear family or slightly extended family, there is considerable variation from this picture. Many people in the case study region live together as one household without necessarily having any blood relation at all. People join the households of their relatives or friends, children are sent to relatives' households during hard times, and orphans are accommodated by relatives and/or neighbours. Households pool and share their resources, and tend to have a single individual who makes the key decisions for the household (such as how to invest savings). These household heads may be male or female, and in the event of the head dying it is usually the spouse who becomes the new head. If the deceased household head had no spouse, one of the other adult members of the household will take over this role.

3.15

In our model, a household is defined as several agents (typically but not necessarily related) living together where all income and available resources are pooled and shared. Each household has a head, chosen randomly from the available adults at initialization, and if this head dies the role is taken on either by the deceased's spouse or some other random adult in the household. This random choice of head probably does not correctly reflect reality, but is used in the absence of further information. The initial configuration of households is a diverse collection of agents typically containing a mixture of married couples, unmarried adults, seniors and children. As the simulation progresses, household composition changes with the birth of children, death of members, and the absorption of unsupported members into other households, when there are no remaining adults. This change in household composition is an important indicator of the effect of stressors. Based on the available evidence ([Drimie and Ziervogel 2006](#)), a typical household size ranges from 7 to 10 members.

Household income sources

3.16

In contrast to many other countries in Africa, South Africa has a social support system which provides grants of various types to the people. The various types of grants provide the main source of income, sufficient in many cases to support an entire household (Pronyk 2002; Ziervogel et al. 2005, 2006b). A significant proportion of the grant money is essentially spent on food. This is followed by transport and medical expenses and for membership fees to various organizations. Three basic types of grants, listed in Table 2 are available.

Table 2: Available grants

Grant Type	Specification
Child Support Grant	For children under the age of 7.
Disability Grant	For adults suffering from HIV/AIDS. Not all qualifying adults apply for this grant as there is a social stigma when an individual is known to be infected.
Old-age Pension	Seniors may receive this grant from the age of 55 for women and the age of 60 for men.

Another significant source of income comes from individuals who have found employment, either within the village and surroundings or who have migrated further (Posel 2001). Those still living at home will contribute their entire earnings to the household, whereas those who have migrated will send home a proportion of their earnings.

Marriage and creation of households

3.17

Although several couples may live in the same household, occasionally new households are established when couples marry. For single adults, marriage partners are selected randomly. The only restrictions in the model currently are that the selected partner must also be adult, and the incest taboo is observed for the nuclear family. A significant feature of marriage in South Africa is the paying of the bride price (*lebola*) by the groom to the bride's family—a value of at least 1000 Rand. Moreover, in order to establish a new household, the households of each partner in the marriage contribute money. If a new household is established, it is considered to be part of the groom's extended family; if not, the bride joins the groom's household.

3.18

The model checks if a couple is alive and if a new birth is possible as follows:

$$\text{Create child agent : } \left\{ \begin{array}{l} \text{TRUE, IF (Chances for birth) AND (Birth Possible)} \\ \text{FALSE, otherwise} \end{array} \right\}$$

Birth Possible ← If (mother is well or HIV+ and fertility exists) and at least one year passed since last birth)

3.19

Fertility of women suffering from HIV declines with the incubation period. This process has been reported in appendix 'C'. One may expect 2 to 3 new children born to a couple, provided that both the husband and wife remain alive during that time. The chance for new birth is a parameter.

Accommodating dissolved households

3.20

A key role of an extended family is the accommodation of the dependents of a household when no adults are left to look after them (Heuveline et al. 2003; Heuveline 2004; Kalipeni et al. 2004). Strong kinship ties have long been understood as perpetuators against the socioeconomic stressors in the sub-Saharan region (Steinberg et al. 2002). However, it has been a growing concern of stakeholders and funding organizations that this long trusted safety-net is no longer effective against the increased mortality rates brought about by HIV/AIDS.

3.21

Households have an incentive to accommodate orphans because of the child support grants to which they are entitled. Furthermore, if children are accommodated by another household while their parents migrate for work; these hosting households will receive a share of the parents' incomes. On the other hand, these potential sources of household income must be balanced against the ability to provide food for the household members. In our model, the accommodation process triggers when no adults or seniors remain in a household. If grandparents of the children exist the children are accommodated in their household. Otherwise, they are accommodated in any other household in the extended family. When there is no available household in the extended family, the neighbours accommodate the dependents.

Feeding household members and 'borrowing' food

3.22

At every time step, the household head agent decides how the available food is to be distributed among the household members. An earlier model capturing the effects of climate on livelihood in the region (Bharwani et al. 2005) assumes that food is distributed evenly between the members. However we know from surveys (RADAR 2005) that adults will try to ensure that children are fed before allocating provisions to themselves and food scarcity is too crucial an issue in our studies to ignore this.

3.23

Depending upon the household's income for the month, the household head decides how much money will be spent on food. This food is then distributed to the agents in the household, with the children being fed first. Adults, who go hungry will, with some probability, attempt to 'borrow' food from their friends. Help is provided, if possible, with an expectation of reciprocal action at a later time (Ziervogel et al. 2006b; Ziervogel forthcoming). In the model the chance of requesting food from friends is set to 25%—a value taken from anecdotal evidence that requires further data.

Table 3: Outline of the main flow of a simulation run in the model. Pseudocode for the procedures which have not been discussed in this section are presented in the appendices B and C

```

Initialization:
1. Set a proportion {parameter} of adult male agents on migration
//Mostly, adult agents go on migration
2. Assign a proportion {parameter} of households to members of randomly chosen funeral clubs
Main Schedule: Runs for n time steps.
1. For each agent ∈ Agents
    call agent.step (current_time) //agent's step function
    //Introduce HIV incidence to uninfected agents in the population.
2. call HIV_Incidence (current_time)
3. purgeDeadAgents() //remove all dead agents
4. call allocate_grants_to_eligible_agents ()
5. For each household ∈ Households_with_no_Guardians
    //accommodate dependents of dissolved household
    call purgeHouseholds ()

```

```

6.i. If ((there exists a couple in a household)
    and (can afford a new house))
    call create_new_household (couple)
6.ii. For each household ∈ Households
    For each couple ∈ household
    If (couple.birth_Possible())
        Call create_child_agent (current_time)
7. For each household ∈ Household
    call household.step (current_time) //household's step function
8.i. For each stokvel ∈ Stokvels //(savings clubs)
    call stokvel.step() //savings club rotation
8.ii. For each club ∈ Funeral_Clubs
    call club.step() //give money to requesting households
9. If (Marriage_Probability)
    //find random male and female from two different households
    //and create new couple.
    call marriage ()
10. End

```

Dynamic Social Networks

4.1

The model adopts a multi-relational social network scheme based on two levels of abstraction as described by Alam and Meyer (2006). Two network layers are considered, one on the level of individuals and one on the level of households. The networks discussed in this paper are dynamic in the sense that households may disintegrate, while new ones are created, and the relationships among the members of the networks change over time. In case of networks involving individual agents, ties are built and broken when the agents are born and die during the simulation run.

Networks Generated from Social Processes

Households' social neighbourhood

4.2

Households in the model have a social neighbourhood space. As actual empirical data on the structure of these networks is a focus of ongoing fieldwork, we have assumed a small-world network with a low clustering coefficient. This assumption is supported by several other studies conducted in the region, e.g. (Quinlan et al. 2005; Ziervogel et al. forthcoming). Neighbours provide mutual support through lending food etc. to each other. The social neighbourhood also provides support to orphans and dependants of a dissolved household in case the extended family fails to do so. Figure 1 illustrates the households linked by their social neighbourhood.

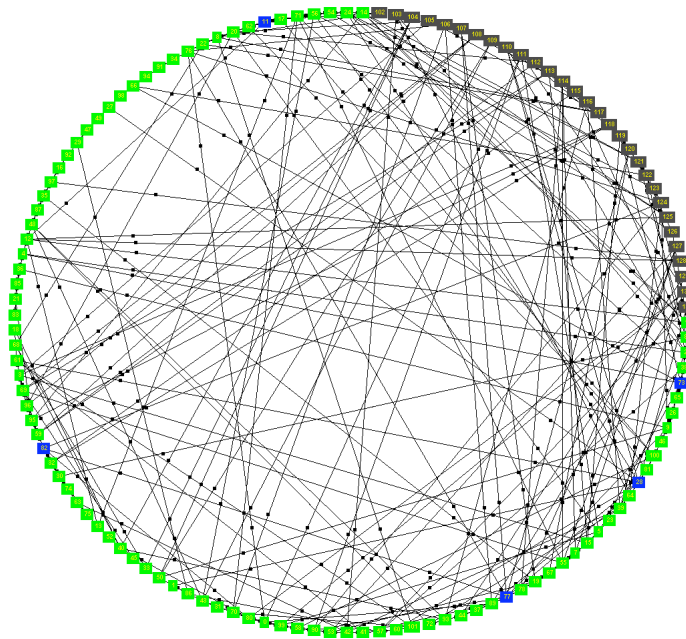


Figure 1. Example of a social neighbourhood space of the village households in the model. The blue squares indicate households that have accommodated members of dissolved households

Agents' friendship networks

4.3

The model also contains a friendship network comprising of individual agents. Since no empirical data was available from the case study region we based the construction of this network on several simple assumptions. Friendship is a symmetric relation. At initialization, no two friends belong to the same household, but this may change over time as the household compositions change (for example due to marriage). We have restricted the friendship network to adult agents. There is an upper limit (5-7) for the number of friends agents may have at initialization, when each agent has a varying number of friends chosen uniform randomly from (0, upper-limit-for-friends). Figure 2 gives a snapshot of the adult agents' friendship network.

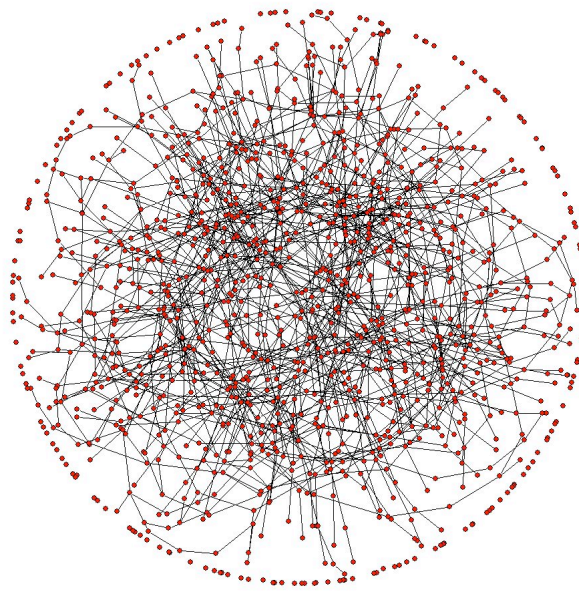


Figure 2. Example of the adult agents' friend network

Extended family network

4.4

As discussed earlier the extended family network is crucial to accommodating orphans when there is no one left to look after them. Marriages are the way through which households get connected to the extended family network. Hence, the network may be perceived as overlapping clusters of households. At the start of the simulation households are initialized with no extended family networks. The households are nevertheless linked via the social neighbourhood shown in Figure 1. As the simulation proceeds and marriages occur, the extended family network grows. Alternatively, one can initialize the model with a pre-existing kinship network. In this case the model establishes extended family links to randomly chosen households, where the number of links assigned to each household is a parameter.

Savings clubs ('stokvels')

4.5

The social neighbours form the basis for informal savings clubs, known as stokvels. Members of a stokvel pay a mutually agreed sum into the club every month. The cumulative savings of the group are then rotated to each member of the group on a regular basis. After everyone has had their turn in receiving the contributions, the group may disband or start another cycle. Female household heads with higher literacy are usually the coordinators of these savings clubs (Foster 2005; Verhoef 2001). We model this by introducing the role of 'facilitators'^[9] for a certain proportion of agents. Facilitators are able to initiate a savings club by inviting other agents and run the club after its formation. Figure 3 shows the evolution of savings club memberships over time.

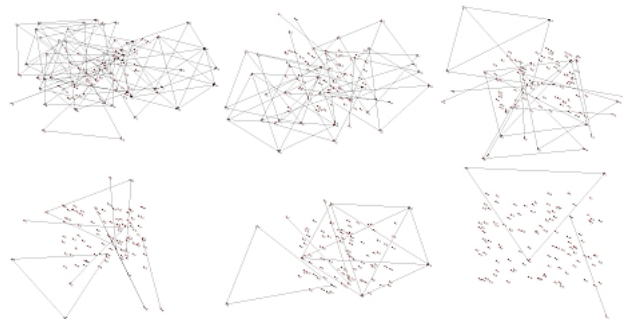


Figure 3. Snapshots of the savings club memberships

Funeral clubs

4.6

The increasing number of deaths in the sub-Saharan region endangers the community structure. Death of an extended family member constitutes a significant financial burden and in reaction to this, many households belong to funeral clubs. These clubs provide money and other forms of aid to the bereaved families. In contrast to the informal stokvels, funeral clubs are usually institutionalized and may be receiving money from aid agencies. Members of these clubs pay monthly dues. The number of funeral clubs is a parameter in the model and each club is created with initial funds at initialization. Each funeral club membership consists of a star-like network of member households.

Migration and Role of Social Networks

4.7

Migration, according to the stakeholders, is perceived as a long-term strategy to secure employment and hence cope better with stressors (Seager et al. 2005; Zervogel et al. 2006b). For many stakeholders, migration is also considered as the final resort (Brunner 2002; Walker 2006; Werth and Moss 2007). Having a relative or a friend in a city plays a pivotal role in an individual's decision to migrate. Social links therefore are central to the process of migration. At initialization, a proportion of the agents are assigned 'migrated' status. These agents have friendship and extended family ties and each belongs to a particular household. These networks provide the necessary links to encourage further agents to migrate later on.

4.8

The already migrated agents may be married and have friends and extended family members in the village. At every time step, adult agents in the village review whether they should migrate or not. They have to be able to work as discussed previously, which is a pre-condition for migration.

4.9

An agent's decision to migrate is stated as follows:

```

If (there are children in the household)
    AND (household members are hungry)
    AND (household can afford travel expenditure)
Then (decide to migrate)
  
```

4.10

Social networks are important for an individual's migration. Having decided to migrate, an agent looks to their relatives and friends who migrated earlier on. The two networks, in this case, are quite likely to overlap. We have restricted the number of tries chosen randomly with the number of already migrated agents as the upper limit. This is done because agents have varying and limited access to those already migrated.

Discussion of our approach on modelling the social networks

4.11

An important problem is how social processes constrain the dynamics of the generated networks at different levels. Ernst et al. (2006) used multiple layers of networks in their land reclamation model. What is also worth investigating is whether and how the networks constrain agents' decisions. This we briefly present in the context of our simulation model. However, we believe that it is possible to look for and/or construct social simulation models from various domains and show that this is indeed a property of the agent-based social network. Carley (2003) describes their notion of dynamic network analysis by means of a 'meta-matrix'. So far we are unaware of any agent-based social simulation paper that has highlighted this *layering* of dynamic social networks.

4.12

It is straightforward to think of situations where the social processes affect the generated networks. In our context, the traditional strong extended family system in the sub-Saharan region directly results in building ties among households. Marriage, even when there is no clear-cut pattern, not only results in a new household in the community; it also brings together households that might otherwise be unrelated. A household head's decision to join a burial society is strongly influenced by the memberships of other households in the extended family. On the other hand, the number and sizes of the savings clubs in a community depends upon a household's current economic status and its social links. A household's dissolution and the accommodation of the dependents by their relatives affect the community's social links. Orphans are typically accommodated by their nearest relatives. This ceases to hold when the nearest relative households are themselves on the verge of disintegrating. In that case, the orphans are accommodated by other households in the extended family. As the accommodating household inherits whatever assets the dissolved household possessed, there is an incentive behind this decision. The topology of the community structure is thus affected.

4.13

The network—represented at different levels—constrains an individual's decision and thus may affect the social processes on the whole. Starting from agents belonging to the same households, key decisions are usually taken by the household head. Friendship is a dynamic process in our model and an adult agent's friends change over time. However, an agent's friendship ties do not influence their joining a savings club unless they themselves become the head of their household. One way of determining the viability of a community structure could be the number of households and their size. A new household adds to the community network and builds new social ties with their neighbours. It is also an indicator that at least some couples in the community are able to build a house of their own. However, if there are job losses, or very high health expenses due to HIV/AIDS, couples will remain in their parents' household and refrain from starting their own. Although this may be perceived as a good strategy to pool the available resources, it may have drastic effects on the entire household later on. Increasing a household's size is likely to result in further shortages of food and an increasing number of children left without care.

Simulation Results

5.1

The model can be run and investigated in numerous ways. The social processes bring the opportunity of exploring a vast range of scenarios concerning the effect of HIV/AIDS on individuals and communities, the impact of government grants, and the interplay of social networks etc. Here we select some scenarios focusing on how far the overlapping nature of social networks helps in coping with the socioeconomic stressors.

5.2

For all cases, the following parameters have remained fixed: initial number of households (100)^[10], initial HIV/AIDS prevalence (20%) and child birth rate (30%). Initial number of agents in the village ranges from 600 to 900 (an average household consists of 7–10 individuals). All simulation runs in this setup had the wealth of households initialized randomly from a range of (1500, 2500) Rand. Appendix 'A' provides a glossary of the model's parameters and their values used in the simulation runs reported in this paper. Unless mentioned otherwise in the following subsections, the values of these parameters have been kept the same as in the glossary. The scenarios have been adapted from fieldwork researchers and social scientists, e.g. Clark et al. (2006), Drimie (2002) and Heuveline (2004).

Role of social networks in accommodating dissolved households

5.3

Households depending upon the income of a single member are most susceptible to dissolve in case of the breadwinner's death. The remaining members, in most case children, will suffer badly. Extended family are generally expected to accommodate orphans and disabled senior members when there is no one left to look after them. While accommodating children and pension-holders brings the incentive of child grants and pensions, an increase in a household's size can increase its expenses. Within our model's framework we investigate this phenomenon for slightly different scenarios.

5.4

We used five different settings, each summarizing a suite of 30 simulation runs. Concentration of extended family relations was dense, medium or sparse in different scenarios. Starting from a densely connected extended family network implies that households have been assigned moieties at the start that become denser as the simulation proceeds. In the first setting, we have used an initial size of 11 households related to each other. The idea is to assign each household highly clustered family links in the beginning. A medium connected extended family network starts with 5 households being related at the start. For 'loosely' connected extended family network family ties are solely established via marriage. For all the first three settings, further links are then established over the simulation run as a result of marriages in the community. Figure 4 shows households having highly clustered initial extended family links (right), while extended family links formed only as result of marriages during the run (left).

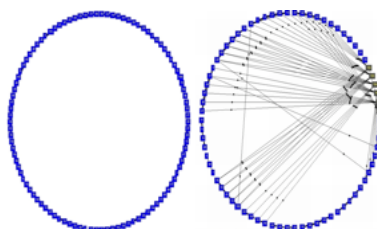


Figure 4. Two examples of an extended family network at the start of a simulation run: (left) when households build links purely on the basis of marriages during the simulation; (right) random initial assignment of households in moieties

5.5

As described earlier, the model has a social neighbourhood for the households in the village community. Unfortunately, we do not have evidence on how the households are linked socially and physically. Anecdotal accounts from our case study partners suggest a small-world type of a network, which is not very surprising for the case study region. In all the five settings presented here, the social neighbourhood of the households has been linked via the Watts–Strogatz method (Watts 2003). The effect of different configurations for the households' social neighbourhood on the simulation outcome is investigated later in this paper. For the first three settings, where both the extended family and the social neighbourhood are relied on for accommodation of dependents, the default Watts–Strogatz re-wiring probability was set to 0.2. ^[11]

5.6

The last two settings investigate the role of the social neighbourhood in accommodating households alone. For these settings, we ran simulations with two different re-wiring probabilities for initial links in the social neighbourhood network: 0.2 (as above) and 0.1, respectively.

5.7

Relatives being also neighbours provide the best safeguard for orphans and disabled individuals. The model's representation for this overlapping of ties gives the best results where relatives' households are located in proximity. Strong overlapping of the two modes of households' networks explains this fact. Nevertheless, this safeguard no longer remains efficient when the extended family's role ceases to be viable.

5.8

When there is no kinship network available as backup, the neighbourhood alone performs poorly in taking care of the dissolved households. The two bottom series in figure 5 show how the number of accommodating households is affected when only the social neighbourhood remains to take care of orphans. As expected, only multiple and overlapping social networks bring forth any sustainability to the individuals. The role of kinship networks as argued in e.g. Kalipeni et al. (2004) and Drimie (2002) is highlighted in the context of this particular scenario.

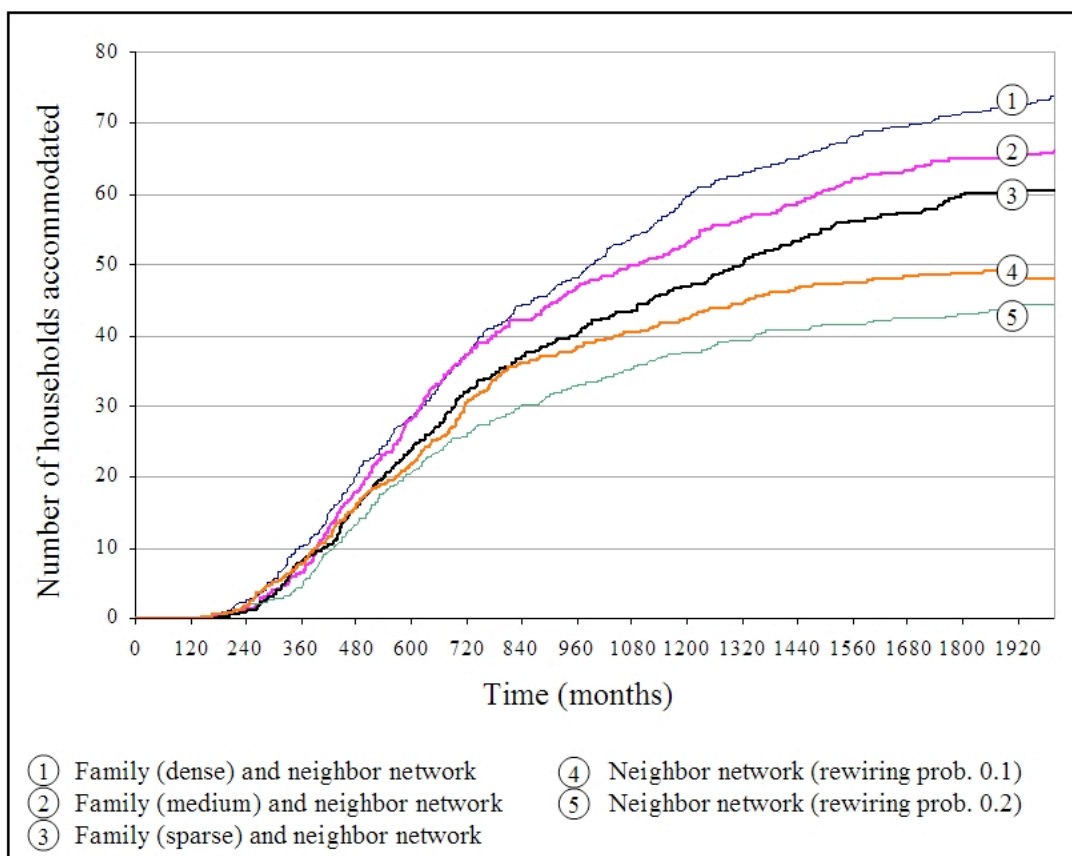


Figure 5. Accommodation of dissolved households in five different settings

5.9

With a higher clustering coefficient (i.e. the smaller rewiring probability of 0.1), the process of accommodating the dependents performed slightly better than in the other case. When only the role of the social neighbourhood is investigated, i.e., in the last two scenarios, one might expect a denser network to perform better. However, the Watts-Strogatz linking of the households defining the social neighbourhood only occurs at the start of the simulation. This can be explained from the fact that network ties and household population evolve as a result of the underlying social processes.

Impact on household's composition due to HIV/AIDS and migration

5.10

Lack of available employment opportunities and income sources in the village forces adults to migrate in order to raise their standard of living. Migration is taken as a long-term strategy, where the household relies on the remittances sent by the migrant member. Not only does the lack of social links constrain an individuals' migration but financial constraints can be a hindrance to migration (section 4). One of several effects of this strategy at the individual and the household level is that elderly people (seniors) have to take the responsibility of looking after themselves and the children. In combination with the HIV/AIDS prevalence, the situation becomes even worse. While migration brings better opportunities for the concerned households, it is possible that it also increases the risk of seniors being burdened with household care and thus aggravating health related issues. Posel and Casale (2003), Walker (2006) and others have reported studies on migration and its impact on the households as stressors. In this paper, we look into one effect of migration both separately and within the context of HIV/AIDS.

5.11

Figure 6 summarizes the results of simulation runs addressing the issue of seniors taking over as household heads in the region. Four experimental settings have been used to investigate the possible combinations of the two major factors: HIV/AIDS incidence and migration. The amount of cash required for migration can significantly affect the results. For all simulation runs reported here we have used the estimated amount of 300 Rand. As there was no evidence available at the time of these experiments we chose a value that produced plausible migration patterns. Since then we were told by our domain experts that as much as 1000 Rand might be required for migration depending upon the travel expenditure. With higher cost, one can expect worse effects on households. We will investigate this further.

5.12

In all the simulation batches, initial households were created with an *adult* agent as the household head, with 50% chance of being a female or male. During a run, the health and burial expenditure of some households increases due to HIV/AIDS. Food expenditure increases when new members join the household. As the majority of the households remain at the 'very poor' level, expenditures cannot be met and consequently the food intake is reduced below subsistence. It is the declining health of the household members, in particular the children, from malnutrition that motivates an agent to consider migration.

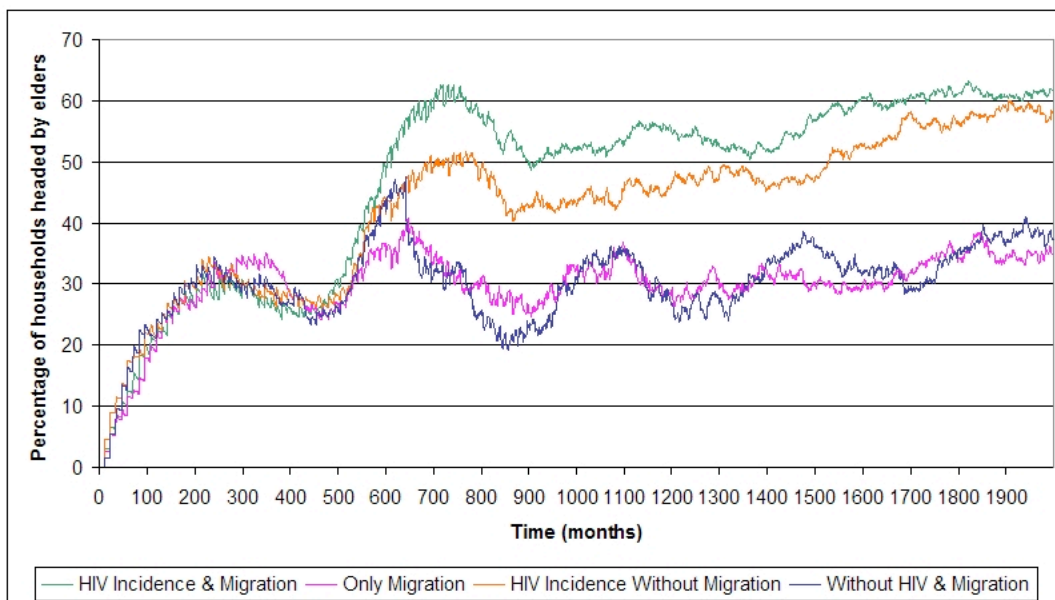


Figure 6. Effect of HIV/AIDS incidence and migration on the age of household heads

5.13

As discussed before, migration of individuals depends upon their household status as well as the availability of their social links. With and without migration, HIV/AIDS can be identified as the primary cause behind seniors taking over as household heads. The reason is, again, the declining health of breadwinner(s) in the household and the subsequent health and funeral expenditure. In a region where AIDS is pandemic, remittance by migrant workers does not help much. Instead, it makes the community structure even more vulnerable as old people take over responsibility for children of their households.

5.14

While migration exacerbates the situation, it alone does not play a very significant role, since without AIDS-related deaths enough capable adults remain in the village. HIV/AIDS as 'the' main stressor has only recently begun to be realized in the region (Ziervogel forthcoming). These scenarios indicate serious policy implications as the government plans to build mining sites in the area. Such initiatives may prove to be a catalyst for an increase of in-migration and HIV/AIDS spread and needs further investigation.

Household economy and food intake

5.15

Modelling complete household economy for our case-study region is not possible as this requires meticulous fieldwork research. However, the impact of households' income via remittances on the availability of food can be investigated based on the available evidence.

5.16

A female household head's primary concern is to feed the household's members, while male household heads may have different concerns. Memberships in the savings clubs are another indicator of how the household head's decisions are affected by the monetary situation: People will join savings clubs when they can afford to pay the monthly fee, and drop out when the household's income is too low.

5.17

We investigate the reciprocal influences of migration, the agents' *feed-status* and savings clubs memberships. In each simulation run, we started with 2 to 3% adult migrant workers, with households' initial income ranging from 500 to 1000 Rand. The amount required for migrating to the city was set to 300 Rand, while the number of funeral clubs was set to be 7.

5.18

Figure 7 presents a sample of 20 runs instead of showing the average number of savings clubs for the simulation runs. These simulations were run for about 100 years time (~1200 ticks). The idea behind this is to find out whether the behaviour remains consistent with understandable variability or not. Typically, savings clubs are expected to remain for a longer period of time (Verhoef 2001; Vermaak 2001). With increasing expenditure and deaths, many household heads had to pull out resulting in a declining trend as the simulations proceeded.

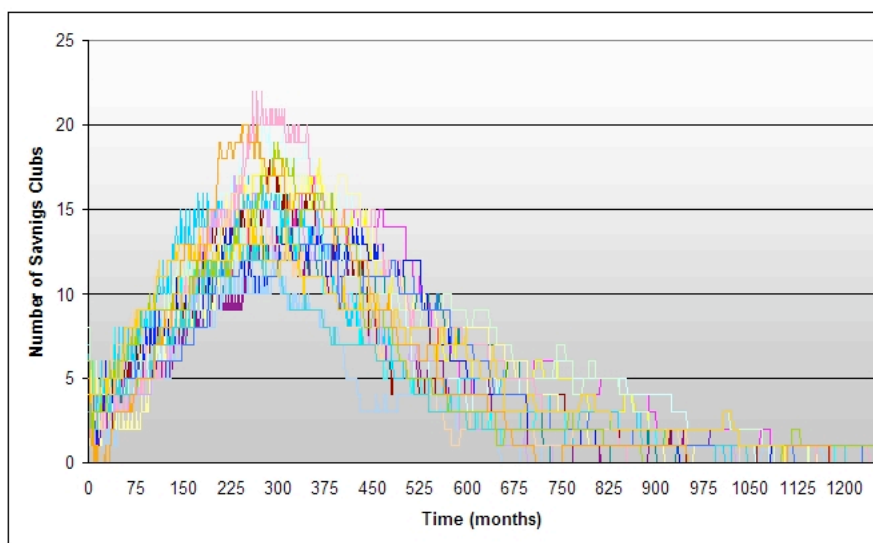


Figure 7. Sample of the 20 simulation runs within the same scenario showing the variability in the number of savings clubs formed over time

5.19

Looking into the number of agents going hungry and the process of migration (cf. figure 8) sheds some light into why the households pulled-out of the savings clubs. This happens either when the head dies or the household's income is badly affected due to health and funeral expenditures. A declining household economy results in an agent migrating and the remittance contributes towards reducing the number of agents going hungry. However, as HIV/AIDS prevalence increases, both savings clubs and agents' remittance break down, as can be seen around the 800th and 1000th simulation month, respectively.

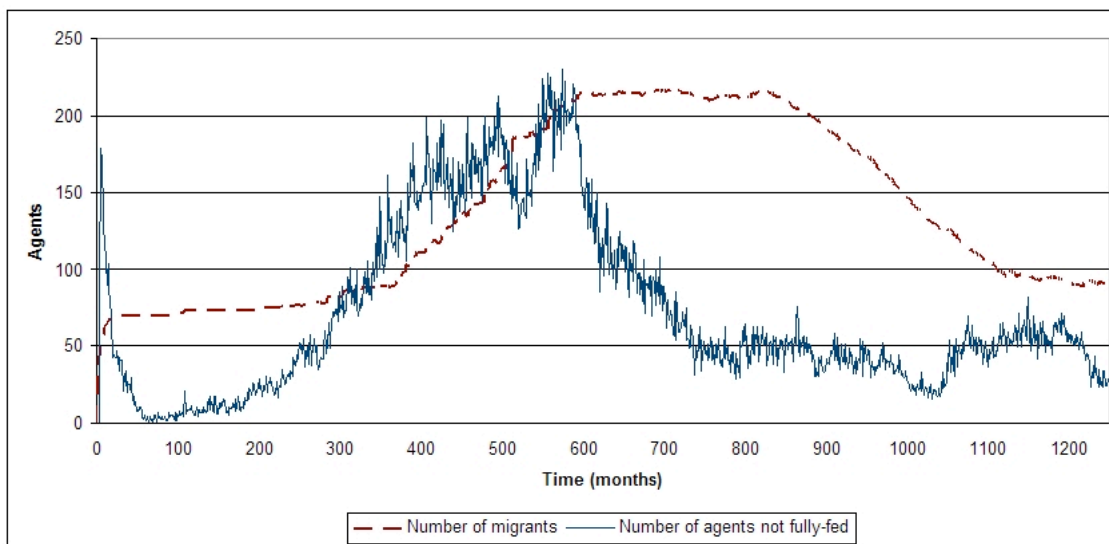


Figure 8. Time series of agents migrating and agents going hungry during the simulated runs

Role of Child Grants and Old-age Pensions

5.20

Unlike many sub-Saharan countries, South Africa has grant schemes for children, orphans, disabled and pensioners as a larger program for poverty alleviation. These grants have been incorporated into the model and the criteria are indicated in section 3 of this paper. Research reported, e.g. in Case et al. (2003), Triegaardt (2005) and Ziervogel et al. (2005) provide further insight to the significance of grants in the region. The child grant policy allows grants to be allocated irrespective of the household composition to which the child belongs (Triegaardt 2005). Although a grant scheme for every child in the household brings opportunities to their families, the amount received is small. In most cases, a household's sole income depends upon the accumulated grant that it gets through all of its members.

5.21

From the anecdotal accounts, only about 50% of the eligible seniors and about one-third of the eligible children receive state pensions/grants in the case study region. The scenario we investigate here is to explore the effect of the grant policy within the scope and limitations of our model. We look into the effect on the households as more eligible seniors start receiving the grants. This happens as the simulation proceeds.

5.22

The question that we ask here: How much does the child grant and old-age pension contribute to households' earnings and their food, health and funeral expenditures?

5.23

The first batch of the simulation runs was set for 100 households, and the number of funeral clubs was set to be 5. The households' size varied from 5 to 9 in each case. Figure 9 summarizes the outcome of these simulations. Results have been averaged over 30 simulation runs. The initial wealth allocated to the households varied uniform randomly in the range of 500–1500 Rand. Only 20% of the eligible seniors were able to receive the grants in this setting. In reality, this proportion varies geographically from 20 to 50% of the seniors receiving pensions.

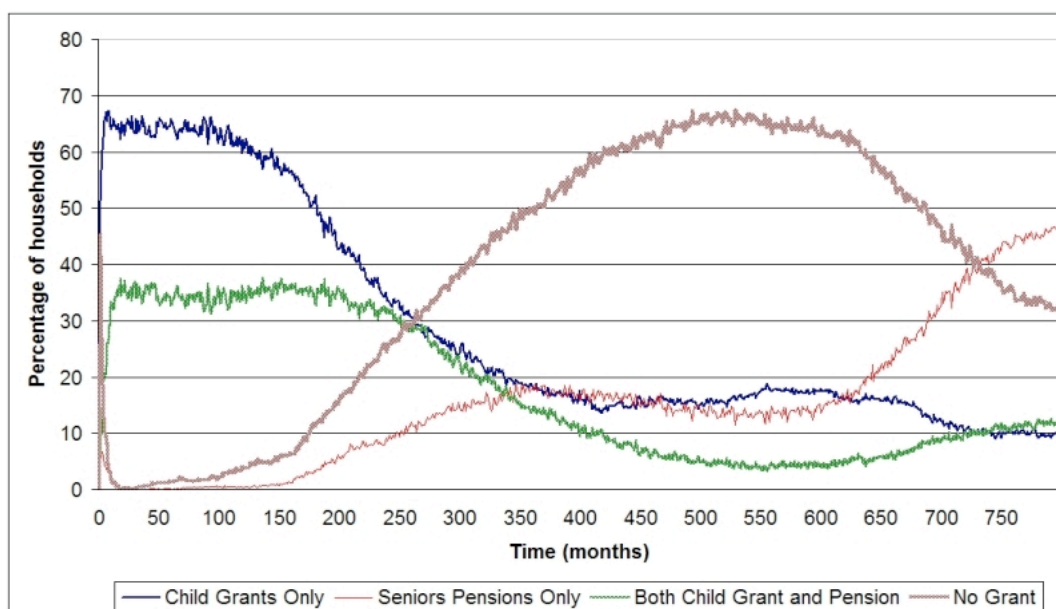


Figure 9. Contributions of child grants and old-age pensions to the households' accumulated income, for 100 households. X-axis: time in months, y-axis: percentage of households

5.24

In Figure 9, most households relied on the child grants only as their major source of income. Only a handful of agents (in this case, 5% of the population, approximately 35) were set to migration at the start. As the simulation proceeds, the proportion of households receiving only child grants decreases. On the other hand, as more seniors start getting pensions, the proportion of households relying solely on pensions increases by the 700th run. However, during a large part of the simulation runs, the majority of the households did not receive any grants at all. This starts to happen around the 300th tick (300th month in a run). This is interesting in the sense that many child agents born during the first several years, become ineligible as child grants are only allocated to children under the age of 7. Moreover, an increasing prevalence of HIV/AIDS affects the fertility of adult female agents (see appendix 'B' for pseudo code), thus decreasing the number of births. Remittance sent by the migrated agents is also a factor in this case.

5.25

In the second batch, the child grant criterion was set up to age 13. Also, the old-age pensions were received by all eligible seniors. The simulation outputs are reported in figure 10. While in the beginning half of the households receive only child grants, the remaining receive both child grants and old-age pensions. This is due to the initial households' composition in the population. Households with children and a couple of 'eligible seniors' are most well-off as both the state pensions and child grants contribute to such households' income. Although with successive generations during the simulation runs the average number

of households receiving no grants increased, the situation did not worsen as in the previous simulation batch.

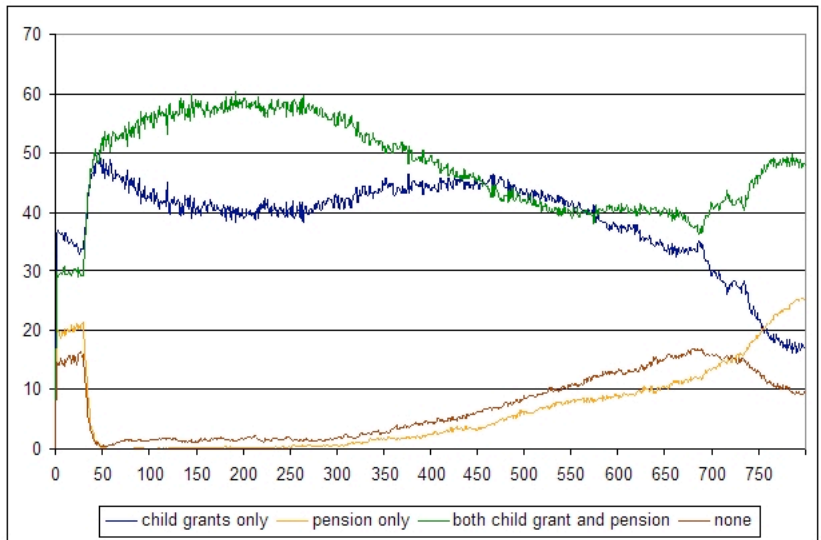


Figure 10. Contributions of child grants and old-age pensions to the households' accumulated income, for 100 households. X-axis: time in months, y-axis: percentage of households

5.26

Following the 2007 South African budget speech [\[12\]](#), state grants have been increased substantially. That is, the child grant, orphan grant, old-age pension and disability grants have been increased to 200 Rand, 620 Rand, 870 Rand and 870 Rand respectively. In order to demonstrate the model's potential as a tool for exploring policy-based scenarios, we investigated the effect the increase in state grants has on the livelihood of the agents. We observe the number of agents who were no fully-fed during a simulation run for the old and latest grant values for cases with and without HIV/AIDS. Figures 11 and 12 summarize the outcome as average of 10 simulation runs for each case. The simulation results provide the reader with an example of the model's potential to explore various policy-related scenarios.

5.27

Figure 11 shows the number of agents who are not fully fed during the simulation with HIV/AIDS incidence in the system. The number of agents going hungry decreases significantly with the newly imposed grants. However, due to HIV/AIDS the population declines as the simulation proceeds.

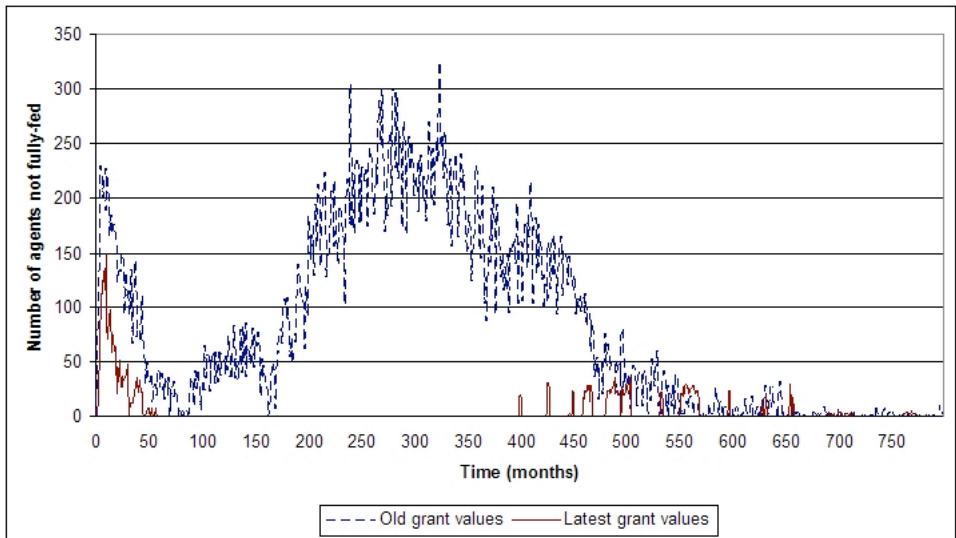


Figure 11. Percentage of agents not fully-fed with prevalence of HIV/AIDS, for old state grant values and the latest grant values from the 2007 budget

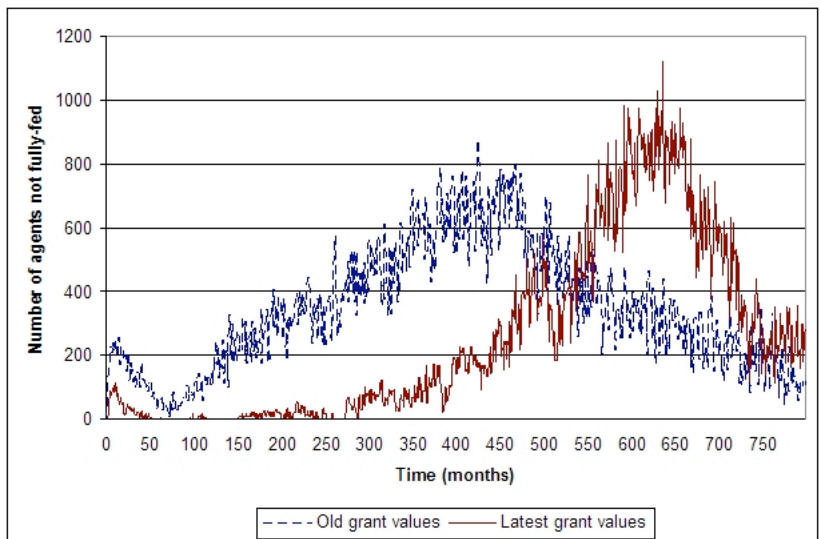


Figure 12. Percentage of agents not fully-fed without HIV/AIDS, for old state grant values and the latest grant values from the 2007 budget

5.28

Figure 12 compares the effect of latest and old grant values on the number of agents not fully-fed in the case with no HIV/AIDS. The simulations were run for a much longer period (i.e. 1500 instead of 800 time steps) as the agents do not die early due to AIDS. Unsurprisingly, the average percentage of agents not being fully-fed is higher throughout the simulation runs for the older grants. The cases in figures 11 and 12 indicate that with an increase in grants, households benefit in terms of coping with the socioeconomic stressors. However, the resulting financial constraints at the state-level can be easily anticipated and will be investigated in our further work.

5.29

From the above scenarios, it is clear that the households' living depends heavily on both child grants and pensions. Households not being able to receive these grants dissolved very soon given the high cost of migration and considerably reduced village-labour. Simulation outcomes in our model are heavily dependent upon the child grant and old-age pension criteria for the agents. The reason is the unavailability of any other source of income in the case study region. A fully-fledged empirical model of the household economy is out of scope of this work. Even so, the role of grants remains highly significant to the households in the Limpopo Province (Ziervogel et al. 2005). The model does reflect the fact that grants, especially the child grants, are the sole source of income for many households in the region. What needs to be further investigated is the effect of different policies for old-age pensions and other forms of grants. Currently, the model serves as a basic test-bed, where further grants policies can be implemented in order to investigate their effects. Involvement of the stakeholders will help in the validation exercises and experimenting policy-related scenarios.

Conclusion and Outlook

6.1

The primary aim of this paper is to demonstrate how a concrete problem based on a real case study can be used in social simulation. The input to the model has been taken from the case study fieldworks as well as other published work. The model is intended to be detailed and elaborative in order to capture the effects of the stressors as reported by the domain experts and the stakeholders. We have used a descriptive agent-based simulation approach so that the model development itself is driven by the available evidence and not otherwise. As Axtell (2002) quotes Herbert Simon, "progress in the positive social sciences can only be had, ultimately, from empirical work, no matter how beautiful is one's mathematical theory."

6.2

Despite the many studies conducted by social scientists and epidemiologists etc. (a few of which are cited in this paper), applications of formal techniques for investigation of socioeconomic stressors in the sub-Saharan are few. Lives of individuals have been badly affected due to illness, lack of employment, food scarcity, poor governance and importantly by the impact of HIV/AIDS. Although social networks including friends, extended family or club memberships have helped in coping with stressors in the recent past, this is no longer always the case. Death of an individual may negatively impact the households' livelihood asset, activities and social networks and that in turn may threaten the existence of the entire community.

6.3

The model presented in this paper makes several important contributions. First, it further extends the use of agent-based simulation in an area related to social policy design at the individual and household levels. We believe that agent-based simulation models can contribute towards providing the policy-makers with better understanding of this critical problem. Our model is driven by evidence and is based on real case-study fieldwork, which is uncommon in the area of social simulation.

6.4

An important contribution of this model is that it captures the notion of overlapping social networks at different levels in modelling human social systems. Networks in our model are generated through local social processes irrespective of any starting network topology. Analyzing the dynamics of such networks is an interesting problem itself.

6.5

A limitation of this work is the modelling of agent's behavioural rules. Decisions such as joining the savings clubs or migration or borrowing food require qualitative accounts from the stakeholders and this is not easy. Fieldwork surveys usually report on the quantitative and aggregate statistics. For example, the size of a typical savings club is reported to be 8, which can be used in validating the model. The rules, however, are based on the anecdotal accounts mainly. Implementing such rules in a simulation model identifies gaps in the empirical data, which have been filled-in by plausible assumptions. The model's parameter values based on these assumptions have been stated in appendix 'A'. The model presented in this paper has gone through several iterations, especially regarding agent's decision procedures. This whole modelling process has resulted in the modellers being able to ask new questions about the underlying problem, with successive iterations. We believe the model at this stage is capable of reflecting the 'key' aspects of the case study discussed in this paper.

6.6

Further evidence will be made available to us through our case study partners in the course of the project. This will confirm or guide the elimination of assumptions relying on anecdotal accounts and thus further refine our model. We have, however, demonstrated that agent-based modelling of the complex impacts of HIV/AIDS on social networks in rural South Africa is indeed promising. We expect to investigate various policy-related scenarios such as how the building of dams and development of mines impacts on local livelihoods and HIV/AIDS as next steps. This will be carried out with the involvement of the stakeholders and domain experts.

Notes

¹ UNAIDS: http://data.unaids.org/pub/FactSheet/2006/200605-FS_SubSaharanAfrica_en.pdf

² CAVES (Complexity, Agents, Volatility, Evidence and Scale): <http://caves.cfp.org>

³ RADAR: "Rural AIDS and Development Action Research programme comprises clinical and social intervention research on HIV/AIDS, with an emphasis on developing model approaches that are appropriate and relevant to the rural African context. It is founded on the premise that the HIV epidemic is rooted in biological, behavioural and social processes—reflecting complex and dynamic relationships within countries and between them. Generating an effective response will therefore require a similar diversity of strategies at the level of individuals and populations. RADAR is based in the Limpopo (formerly Northern) Province of South Africa at the Health Systems Development Unit. The programme is a collaboration between the School of Public Health at the University of the Witwatersrand and the London School of Hygiene and Tropical Medicine." <http://www.wits.ac.za/radar/>

⁴ Repast Agent Simulation Toolkit: <http://repast.sourceforge.net/>

⁵ Java Expert System Shell: <http://www.jessrules.com/jess/>

⁶ Pajek (Program for Large Network Analysis): <http://vlado.fmf.uni-lj.si/pub/networks/pajek/>

⁷ see e.g. AVERT (AIDS & HIV Charity) <http://www.avert.org/pregnancy.htm>

⁸ Food and Agriculture Organization (FAO) <http://www.fao.org>

⁹ The idea of 'facilitators' was introduced in the model in order to represent individuals who possess higher coordinating skills and thus play the role in kick-starting stokvels in the model.

¹⁰ Our choice of 100 households is because it approximates a village's population in the region.

¹¹ A re-wiring probability of 0.2 results in a low clustering coefficient score and a low average path length. Thanks to the anonymous referee for pointing this out.

¹² South Africa budget 2007: <http://www.sars.gov.za/budget/documents/budget/2007/guide.pdf>

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Appendix A: Model's Parameters (including constants)

```
//probability that an adult HIV/AIDS agent gets this grant
DISABILITY_GRANT_PROBABILITY = 0.10
PENSION_AGE_FEMALE = 55 years
PENSION_AGE_MALE = 60 years
//the following is same for both female and male agents in the model
MEAN_LIFE_EXPECTANCY = 75 years
STANDARD_DEVIATION_LIFE_EXPECTANCY = 5 years
//Households initialized with wealth chosen randomly from this range:
MIN_STARTING_WEALTH = 500 Rand
MAX_STARTING_WEALTH = 1500 Rand
FUNERAL_CLUB_FEE = 250 Rand
//this is for an adult agent
MIN_MONEY_TO_FEED = 45 Rand
MAX_MONEY_TO_FEED = 65 Rand
//Grant values:
DISABILITY = 300 Rand
PENSION_GRANT = 560 Rand
CHILD_GRANT = 125 Rand
ORPHAN_GRANT = 175 Rand
MARRIAGE_AGE_UPPER_LIMIT = 45 years
//Remittance value of the migrant agents chosen from Normal distribution
MEAN = 200 Rand; STD_DEV = 50 Rand
//the 'grace period' for the number of months a household might benefit from a funeral club without being able to paying the dues
FUNERALCLUB_GRACE = 6 months
//HIV-infected agents' health starts to deteriorate only after some time //could be 6 months - 4 years depending upon the nature of the HIV
INFECTED_LAG = 18 months
//the birth rate is 0.3 per person-year in many of the most affected
BIRTH_PROBABILITY = 0.25
//cost for funeral / burial ... can be as high as 5000 Rand
FUNERAL_COST = 2500 Rand
PROPORTION_OF_FACILITATORS_AT_START = 20%
MINIMUM_MEMBERS_REQUIRED_FOR_SAVINGS_CLUB = 5
HEALTH_EXPENDITURE_FOR_SINGLE_AGENT = 100 Rand
```

Appendix B: Pseudocode for Savings (stokvels) and Funeral Clubs

Table B1: Pseudocode for initiating and joining a savings club and the schedule

Assumptions:

1. Only women household heads join the savings club (stokvel).
2. Some agents are *facilitators* ≤ MAX_FACILITATORS: having, e.g. able to stimulate creating a club etc.

Savings Clubs (Stokvels) Creation Schedule:

1. For all facilitator ∈ Facilitators | isHouseholdHead (facilitator) ∧ joinClub (facilitator)
 - a. For each agent ∈ Agents | isHouseholdHead(agent) ∧ {facilitator.Friend(agent) ∨ facilitator.neighbor(agent)}
 - b. sendInvitation(facilitator, agent)

```

2. For each agent ∈ Agents | isHouseholdHead(agent)
  a. handleInvitation(sender); where sender is the facilitator
  b. If (invitation-accepted) sendAcceptance(agent, sender); else sendRejection(agent, sender)
3. For each facilitator ∈ Facilitators | isHouseholdHead(facilitator)
  If (#acceptances ≥ MIN_CLUB_SIZE) create new savings club
handleInvitation: on receiving the invitation from an facilitator agent to join a new savings club
  If {(joinClub(facilitator) ∧ !memberSavings) sendAcceptance; Else sendRejection
joinClub: a household head agent's decision to join a savings club or not;
  If (household wealth ≥ SAVINGS_CLUB_FEE) join club
Savings Club Rotation Schedule:
1. For each member ∈ Members of the club
  a. If {isDead(member) ∨ isPulledOut(member) remove member
  b. If { not (|Members| ≥ MIN_CLUB_SIZE) } finish club
  c. amount ← amount + member's contribution
2. next candidate gets the lump sum amount

```

Table B2: Pseudocode for the funeral club methods

```

Joining and paying the contributions at a funeral club:
1. A Household joins when there is an adult bereavement due to HIV/AIDS; membership is permanent.
  2. Dues (set fixed) are paid monthly. In case of consecutive default for 'n' months, aid is not given.
Funeral Club Schedule:
1. Receive request for payment from members.
  2. If possible, pay all requesting members the funeral cost
  Else distribute the available funds equally.

```

Appendix C: Pseudocode of processes related to agents and households

Table C1: Estimated energy requirements expressed as a percent of Adult Male. Calculated based on a Tsimane' body weight data, and the FAO/WHO/UNU (1985) equations for estimating energy needs

Sex/ Value	Adults (18-59 yr)	0-2 yr	3-5yr	6-9 yr	10-13 yr	14-17 yr	Elderly (60+ yr)
Males/% of adult male	100	33	48	64	74	87	62
Females: % of adult female	75	35	53	53	66	70	57

Process: Agent's step function (Agent: agent)

```

If (agent is a year older at current tick)
  Then update agent's age
call update_health_status(agent)
If (agent is not dead)
  If (fit_for_labour(agent))
    If (should_migrate) Then set_migrated(agent)
    Else If (gets_village_labour) Then set_onLabour(agent)
  If (last_try_to_join_stokval > 6 months) Then try_join_stokvel
End

```

Process: Updating agent's health status (Agent: agent)

```

If (health_status is HIV) AND (time_since_infected ≥ infected_lag)
  Then fast-decay (health); using sigmoid curve
Else If (agent is old)
  If (health-count is Weak) Then set health_status ← old-age-sickness
  else set health_status ← disabled
else if (agent is adult) or (agent is child)
  if (health-count is weak) then set health_status ← illness
end

```

Process: feeding household agents (agent: household head)

```

for all agents on labour or migration
  set feed-status ← full-fed
;now for the rest of the household
for all agents currently in the household
  ;maize price is set to be 3rand/kg; 10kg assumed for adult male/month
  food-requirement ← add (agent(food-requirement * maize-price))
  if ((can_afford (food-requirement)
    and (not member-funeral-club)
    or ((member-funeral-club) and (can_afford (food-requirement and funeral-club-fee))))

```

```

    set feed-status ← full-fed
else if ((member-funeral-club)
    and (food-requirement + funeral-club-fee ≥ household-wealth))
    for all child agents in the household
        set feed-status ← full-fed
    for all other agents in the household
        if (can_afford 'half-feeding' for all)
            set feed-status ← half-fed
        else
            to agents as possible: set feed-status ← half-fed
            to the rest: set feed-status ← not-fed
end

```

Process: borrow food (agent: adult hungry agent)

```

for all agents in the friendship-network
    if (ask (friend) and friend.can_feed(agent))
        set feed-status ← half-fed

```

```

;procedure: can_feed (agent: borrower)

```

```

    if house.haswealth
        ;lend money to half-feed the borrower agent
        then feed (borrower, half-fed)
end

```

Process: fertility criteria (agent: adult female; current_tick)

```

; this is an abstract implementation
pre-condition: got infected from hiv at time: infected_tick
time-difference ← current_tick - infected_tick
if (time-difference less than 2.5 years)
    then return (chance for fertility: 100%)
else if (time-difference less than 5 years and greater than 2.5 years)
    then return (chance for fertility: 75%)
else if (time-difference less than 7.5 years and greater than 5 years)
    then return (chance for fertility: 55%)
else return (chance for fertility: 40%)
end

```

Process: fit_for_labour (agent: agent; current_tick: return boolean)

```

;this rule is based on an arbitrary assumption
if ((agent is old and health_status is not hiv)
    or ((health_status is hiv) and (time since hiv infection less than infected_lag))
    then return true
else return false
end

```

Process: household step function (household: household)

```

for all agents in the household
    update_cash_in_hand(receive_income(agent))
; deduct household's wealth for food expenditure
call feed_members
call deduct_health_expenditure
; for funeral clubs and stokvels if it is a member
call deduct_clubs_fees
end

```

Process: deduct health expenditure (household: household; current_tick)

for all agents in the household

```
if ((health_status: hiv and time since hiv infection greater than infected_lag)
    or (health_status is illness or old-age-sickness))
    call deduct_wealth(health_expenditure)
```

end

Process: Deduct funeral cost (Household: household; is_Bereaved: true)

; This is an arbitrary assumption

If (cash_in_hand is twice the funeral_cost)

; I am wealthy so I will have a full-fledged funeral arrangement

```
Then call deduct_wealth(funeral_cost)
```

Else

; cost to be born by the household and the extended family network collectively

```
cost ← call calculate_lesser_cost
```

```
call borrow_funeral_cost(cost)
```

end

Process: Borrow funeral cost (Household: household; cost)

If (cannot bear cost)

```
Then for all relative_household in the extended_family_network
```

```
    call ask_contribution_for_funeral (relative_household)
```

End

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