Utrecht University
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Coping with Complexity in Development Studies

An Exploration of Causal Loop Diagrams and Agent-Based Modelling

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Preface

This research fulfils the final requirement for the Master programme Sustainable Development at Utrecht University. More specifically, for the International Development track of this programme. During my time as a student, both of these development terms have proven to be interchangeable, and as such, I was offered the opportunity to define myself.

As a student of Development Studies, with a specialisation in Sustainable Development and a background in European Studies and Artificial Intelligence, my academic career has been characterised by the construction of reality from an interdisciplinary point of view. This was very useful because problems in Development Studies tend to be dependent on such an amount of factors and unknowns that at times any analysis seemed to be viable, yet none satisfactorily. Practically all people I met during my studies and in the field seemed to have grand intentions, but often, they were unable to accomplish the change they envisioned. Or worse, like a Chinese finger trap: the harder they pushed for improvement, the worse situations became.

When I first came across the concepts of Complexity, it intuitively felt right to me. And as a developing field of enquiry, exciting too! Yet, next to its theoretical merits, it was hard to discern any practical implications. More often than not, I stumbled into the following line of critique:

> The diagnosis of complexity is often the endpoint of analysis or critique. An approach or policy is scrutinized and then criticized because it ignores certain elements and the conclusion is the diagnosis of complexity (Nederveen Pieterse, 2004, p. 159).

I do not believe that is a proper way to look at the issue. If something describes the truth, it is important to work with it as best as possible.

In this case, it quickly became apparent to me that we are indeed not able to describe complex systems in their entirety, and we will likely never be able to so, but we are able to develop tools to deal with Complexity more explicitly. I acknowledge that social systems might be among the classes of systems hardest to grasp, yet I also know that Development Studies affects the lives of a great many people in the world. Therefore, I argue that is of vital importance to update current tools of analysis in Development Studies to deal with nonlinearity in more explicit ways. I am convinced that Complexity is aids me to construct a better realty.

Therefore, I am most grateful to my supervisors for allowing me to conduct this research: Dr. Guus van Westen who first planted the seed of Complexity in my mind and Prof. Dr. Bert de Vries whose technical and compassionate advice enabled my intentions to become tangible.

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Acronyms & Definitions

ABM	Agent-based model
CAS	Complex Adaptive System
CLD	Causal Loop Diagram
HIV	Human Immunodeficiency Virus
FAO	Food and Agriculture Organization of the United Nations
Ladino	Honduran Non-Indian
MDG	Millennium Development Goal
NetLogo	Multi-agent programmable modelling environment
NGO	Non-Governmental Organisation
NIE	New Institutional Economics
ODD	Overview, Design concepts, and Details
ODI	Overseas Development Institute
Tawahka	Honduran Amerindians
UN	United Nations
UU	Utrecht University
Vensim	Software for simulating System Dynamics

1. Introduction

> The human mind is not adapted to interpreting how social systems behave. Social systems belong to the class called multi-loop nonlinear feedback systems. In the long history of evolution it has not been necessary until very recent historical times for people to understand complex feedback systems. Evolutionary processes have not given us the mental ability to interpret properly the dynamic behavio[u]r of those complex systems in which we are now imbedded (Forrester, 1995, p. 3).

Current understanding is often based on linear relationships. We distinguish between causes and their corresponding effect and consequentially convince ourselves and others that this is the manner in which these elements behave. Although this has proven to be quite an effective yardstick in some instances, it has proven to be highly inadequate in others. Within the discipline of Development Studies it has become common practice, therefore, to consider contexts holistically. To deal with these contexts, however, students of the discipline are often forced to deconstruct these contexts and divide them in separate elements once more. This is even more the case in the world of development practice and the provision of aid. Donors wish to see explicitly how their money is spent.

Complexity has the explanatory power to deal with contexts as a whole and allows for their definition as complex systems. Complexity has, however, not fully matured yet and as such the insights it already offers are not widely adopted. This thesis is devoted to find out in what way analytical tools can be applied to deal more explicitly with the concepts of Complexity within Development Studies. I argue that there are two distinct aspects of Complexity that need to be taken into account for Development Studies to retain its legitimacy:

1. Contexts should be able to be framed as complex adaptive systems;
2. There should be an instrument that can deal with nonlinearity in instances where linear methods, such as a regression analyses, are clearly not up for the task.

This has led to the formulation of the following two research questions:

Research Question I:
To what extent can reconstructing Complex Adaptive Systems with Causal Loop Diagrams contribute to research in Development Studies?

Research Question II:
To what extent can Agent-Based Models contribute to analysing Complex Adaptive Systems within Development Studies?

Specific information about these methods can be found in chapter 3. For now it suffices to note that these methods have proven to be adequate in other disciplines.

Since this research concerns broad concepts such as Development Studies as a discipline and Complexity, the next chapter explains how they are interpreted throughout this research and in what way they relate to each other. The subsequent chapter delves more into the methodological aspects of this research and further elaborates on the methods that are subject to this investigation. Because both methods will be applied to an existing case study, chapter 4 describes the relevant details of this case study. Chapter 5 is focussed on the first research question and chapter 6 revolves around the second. Chapter 7 then sums up all the findings and provides more clarity about the issues raised in this introduction. Finally chapter 8 discusses suggestions for further research.

2. Theoretical Framework

In this chapter first a short overview of the discipline of Development Studies is provided. Then an explanation of Complexity and its implications follows. The final section then is devoted to the synthesis of these fields of knowledge and discusses in what ways Complexity can and should be integrated within Development Studies.

2.1 Development Studies

Development Studies is concerned with all issues related to development or change in countries that are accepted to be in need of it; that is, related to other countries in the world. Its broad focus is supported by a multidisciplinary approach, originating, and located in, the social sciences. It came into being around the end of the 1960s and was deeply marked by the post-war mindset. It reflects the ideas of the Enlightenment, which are founded on four golden rules: order, reductionism, predictability and determinism (Rihani, 2002). Modernization theory, dependency theory and later the New Institutional Economics (NIE) were deeply immersed in the political-economic ideology. Development was equated with economic development and people were seen as rational actors, adept at maximising profit.

Currently, there is a growing consensus that economic growth is not the equivalent of development, especially not on the state level. Inequalities hurt. Self-esteem, self-respect and improving entitlements have become important topics within Development Studies (Desai & Potter, 2008).

The research practice has been altered too. Postmodernism has made short work of the grand narrative. There are at least as many realities as there are individuals, so improving the reality of distant beneficiaries necessitates understanding their reality. Moreover, any blueprint for progress should as well be abandoned. The context matters and trusting the state to be a proper analytical frame for that context has become a most tricky gamble.

Humans ultimately still being humans, they need strategies to sustain their livelihood. “A livelihood comprises people, their capabilities and their means of living, including food, income and assets” (Chambers & Conway, 1992). The livelihood approach was adopted to take a more holistic account of the factors contributing to both material and non-material well-being (Zoomers, 2008).

So Development Studies is moving away from a focus at economic development on the state level towards empowerment, indigenous knowledge and holism. There is, however, still no definite methodology adopted to combine this to everyone’s satisfaction[1] and the discipline is still in dire need of improved methods to help the poor and powerless. Even worse, “[m]uch development and humanitarian thinking and practice is still trapped in [the old] paradigm” (Foreword by Chambers in Ramalingham, 2008, p. vii).

2.2 Complexity

2.2.1 Concepts of Complexity

Complexity, Complexity Theory or Complexity Science denominate attempts to better understand and deal with systems exhibiting complex phenomena. A real definition of Complexity, however, has still not been created. Scientist from all corners of academia have tried in vain formulate a principle that unifies the concepts of Complexity. Therefore, Complexity itself, as all concepts related to it, remain fuzzy to a certain extent. It gets even fuzzier because of all the different disciplines working on it (Mitchell, 2009, p. xii). In an attempt to get closer to the common denominator, Gershenson

[1] See for instance the current status of the Millennium Development Goals (UN, 2011).

(2008) has interviewed the most prominent figures in the field of Complexity and asked them all a set of five identical questions. Although some general notions can be discernible from most of these answers, the interviewees seem to prioritise them differently, as do they emphasise different aspects. As a consequence, the easy way out would be to consider Complexity as a work-in-progress and postpone any explicit application until the 'experts' have found a definite way for us to work with. The interviewees, however, do agree on the fact that Complexity entails principles that are real and all around us. Moreover, many of the concepts of Complexity replace prevailing notions in contemporary Western society. So in order to deal with Complexity in the context of Development Studies it is important to apply selection and prioritisation ourselves too. Thankfully, Ramalingham and others at the Overseas Development Institute (ODI) have already carried out this task meticulously in 2008. This section is loosely based on the concepts they have selected and offers a brief overview of what they entails in general. It is only in section 2.3 that the significance of these concepts to Development Studies is elucidated. Before continuing, it is important to note that Complexity can only emerge within the context of a system. A system is a set of interacting elements that together form an integrated whole. It has a boundary and exhibits system behaviour. The following concepts will either relate to the micro-level behaviour of the elements within the system, the meso-level behaviour of groupings of those elements or the macro-level behaviour of the system as a whole. Of course, systems can be nested in system that are nested in systems ad infinitum, such as a cell which is part of an ant, which is part of the populace of an anthill, which is part of the local ecosystem, etc. As such, the above micro-, meso- and macro-level distinction will not be made explicit.

Interconnectedness and interdependence

As stated above, the elements in a system in are interconnected and interdependent. These relationships are the basic reason why events in one part of the system can have far-reaching consequences in other parts of the system.

Feedback

The relations between elements allow for direct and indirect feedback. Elements influence other elements, but are in turn influenced again by the elements they influenced themselves. Positive feedback amplifies change and "is at the heart of phrases such as 'vicious circles' or 'self-fulfilling prophecies' (Ramalingham et al., 2008). Negative feedback on the other hand dampens change and allows for systems to be in equilibrium.

When considering social systems, reflexivity is a notable form of feedback.

Emergence

In complex systems behaviour can emerge from the interaction of elements that is often unexpected. 'The whole is more than the sum of its part' is an expression frequently uttered to designate this phenomenon. The brain and the Internet are noteworthy examples of emergence. "The appearance of emergent properties is the essential feature of complex systems" (Boccara, 2010, p. 23).

Nonlinearity

Nonlinearity can be best explained by focussing on linearity first. Linearity entails that the output is proportional to the input. So in contrast to emergence, the whole is exactly the sum of its part and can also be broken down as such. Understanding the different elements allows for understanding the entire system. Linear behaviour takes place when the system is at, or close to, equilibrium. Thus, nonlinearity entails that a system can only be understood when taken as a whole. As will be illustrated in the next section, this concept is very important as most contemporary modes of scientific analysis are still based on linearity.

A telling example of nonlinearity is for instance the provision of humanitarian assistance: at times it directly helps its beneficiaries sustaining their livelihood; at times it makes the situation worse by bolstering corrupt institutions; and at times it is to no avail as the provided assistance does not meet

the local needs. It is hard to generalise the effect of humanitarian assistance on the well-being of the deprived as any success also heavily depends on co-interacting factors.

Sensitivity to initial conditions
The concepts described above cause the value of every element or relation to be of significance. In the long term, small initial changes might have profound consequences. The butterfly effect is the most famous example.

Adaptive agents
Adaptive agents are instances of elements that respond to each other and the system. They are autonomous, goal directed and can learn and adept their behaviour (Zhu, 2011, p. 988). Evidently, "[h]uman beings are adaptive agents *par excellence"* (Ramalingham et al., 2008, p. 44).
The class of complex systems that are made up of adaptive agents are considered Complex Adaptive Systems (CAS). Thus when dealing with a social system, one generally speaks of a CAS. Social systems "present researchers with a unique set of theoretical and methodological challenges." (Castellani & Hafferty, 2009, p. 69).

Self-organisation
This concept relates to the manner in which adaptive agents engage in micro-scale strategies that produce macro-scale patterns. Adam Smith's 'Invisible Hand' is a powerful example of self-organisation.

Co-evolution
Co-evolution refers to the intimate relationship between an agent with another agent, an element or the broader context that causes its development to be adaptive to the development of the other. CAS are characterised by the co-evolution of adaptive agents and their contexts. In the case of human beings, this is often caused by learning and the development of alternative ways to shape the environment (Israel & Wolf-Branigin, 2011).

2.2.2 Implications of Complexity & the Social Sciences

Traditional research that focuses on only one thing, and thus deals with an independent variable, is unrealistic (Ramalingham, 2008). Statistical methods oriented at linear relationships rely on a situation that is too simplistic and the quantitative approach offers a false sense of objectivity. It is not possible to hold other things equal (*ceteris paribus*) because all elements are interconnected and react strongly to each other.

Another pitfall is the fact that one may falsely ascribe certain characteristics to a part of the system while the entire system may be responsible (Jones, 2011). Or in practice one might overly focus on a particular dimension of the system, while this has severe adverse consequences in another dimension (Ramalingham et al., 2008).
Colliers (2010) addresses these difficulties posed by Complexity, even arguing it to be an epistemological crisis: simple reductionism is no longer deemed adequate, while completely embracing Complexity may lead to relativism. Nonetheless, since these ideas guide real action, it is necessary to solve this crisis. Also Ramalingham et al. (2008) deal with this issue and they contend that many implications are therefore only possible at a meta-level: "they suggest new ways to think about problems and new questions that should be posed and answered, rather than concrete steps that should be taken as a result" (p. ix). It is important to consider problems from a systems perspective, especially within the Social Sciences, where the issues under investigation are part of CAS'. Any other method can no longer be considered legitimate.

2.3 Synthesis

While Complexity has been upcoming in the natural sciences for at least half a century, it has only permeated, albeit with an increasingly rapid pace, the social sciences little more than a decade ago (Rihani, 2002; Castellini & Hafferty, 2009). In Sociology, John Urry has coined it the 'Complexity Turn'. This has led to the establishment of a new sociological field of inquiry called Sociology and Complexity Science, or SACS for short (Castellini & Hafferty, 2009). Within Development Studies, various scholars and institutions (e.g. Rihani, 2002; ODI, 2008/2011) have attempted to achieve acceptance and understanding of Complexity in a similar vain. These ideas, however, are far from being picked-up by the community as a whole. Moreover, due to the fuzziness of Complexity as described above, the concepts are being touched upon only lightly and selectively. Even by the proponents of Complexity mentioned before, application of Complexity is often restricted to policy advice or a vague provision of general methods to deal with it in the field. Of course, any acceptance of Complexity is welcome, if only for reasons of legitimacy. Yet it is also important to consider manners in which Complexity can become explicit. When dealing with complex systems, it should become common practice to identify situations as such: what elements can be identified, how do they interact and what are the boundaries of the system? That is also the reason the members of SACS argue that "all sociologists, regardless of their area of inquiry, should have a basic knowledge of the leading scholars and areas of research in SACS." (Castellini & Hafferty, 2009, p. 234). In this section various proposed applications of Complexity within development practice and Development Studies are discussed. Implicitly, it is centred along the lines of the three notions that have been discussed in section 2.1, namely: holism, empowerment and indigenous knowledge.

> Development unfolds in diverse contexts of relations of power, cultural values, social practices, ecological conditions and historical itineraries. Development is intrinsically contextual.
> (Nederveen, 2004, p. 155)

Within Development Studies the context matters greatly. The reason for that is because every system under investigation is a CAS. As the concepts in the previous section have illustrated, it is impossible for any complex system to behave identically, especially when it is made up of human beings (i.e. adaptive agents). Therefore, both perspectives agree that any set of rules is not transferable to any other system or context. Warner (2001) contends that it is important to pay more attention to patterns. Interventions can only be successful when they enable beneficiaries to be adaptive to the dynamics within the social system. Thus the poor and powerless should still be empowered, but only in conjunction with a holistic framework. This not only necessitates a new method of analysis, but also one of action. Funding should become more flexible and less dependent on stringent targets and requirements (Ramalingham et al., 2008). Moreover, "greater attention must be paid to concerns throughout an intervention, rather than prior to it" (Jones, 2011, p. 12). Cilliers (2010) also argues for the necessity of participatory interventions as that is the only method of attuning any approach to the local reality. Consequentially, the debate of the cost-effectiveness of a specific service should become subordinate to the appropriateness of that service within the whole system. This is even more so when other development programs are targeting the same system. Development projects should be part of an integrated approach, both integrated in the context as well as in the deliverance of a well-coordinated service (Nordtveit, 2010).

Nevertheless, Complexity still has not yet led to specific prescriptions. Nordtveit (2010), for instance, claims that desirable development can only be truly reached by removing the barriers to self-organisation in order for participants to be able to move the system to a desirable trajectory. Ramalingham et al. (2008) discuss the merits of identifying leverage points in order to tip the system from one state to another. Especially with this last method, however, it becomes necessary to have extensive knowledge about the complex system under consideration.

The advantage of concepts of complexity is that the mathematical relationships between the elements of a system can be defined precisely (Ramalingham et al., 2008; Vries, 2010). As such, it is possible to represent complex systems with modern mathematical simulation techniques (Vries, 2010). Jones (2011) contends that it is these very simulation models which uniquely offer the opportunity to address adaptation and determinism in complex social systems. The most appropriate simulation model for the task at hand is arguably an Agent-Based Model (ABM) as it has adaptive agents as its focus, offering tools to deal with all complexities associated with this kind of agent. Obviously, a model is still a simplification of reality. Neither should it be claimed that human beings can be grasped by a model in their entirety. Yet, I do claim that relations of relevance in Development Studies can be better explained by models such as ABMs, then, for instance, a simple regression analysis which is applied far more often in the discipline. Therefore, ABMs are an important focus of this study and they will be discussed more thoroughly in the next chapter.

Throughout this section concepts of Complexity and Development Studies have been linked with one another. This has indeed served the purpose of illustrating why both ways of grasping reality fit well together, and why a transition to Complexity would not be as far-fetched as one might expect. Nevertheless, it is important to bear in mind that the concepts of Complexity do not have to be imported mindlessly, or that the current insights of Development Studies should be thrown away with the bathwater. Instead, as Byrne (2005) argues too in the case of Sociology, current tools and theories should be reconstructed in complexity terms. Part of that reconstruction, I argue, is applying complementary tools of analysis. Next to ABMs, this research therefore focuses on Causal Loop Diagrams (CLD). Although CLDs actually are part of the analytical repertoire of System Dynamics instead of Complexity Science, it will become apparent in the next chapter that CLDs are an excellent mode of reconstruction.

3. Methodological Framework

This research is of an exploratory or experimental nature, aimed at testing two types of models for their appropriateness as methodologies. To do so, a learning-by-doing approach is applied and, as such, there are two distinct levels which require elaboration in this chapter:

1. The level which is concerned with answering the research questions;
2. The level which is concerned with the application of the models under investigation.

It is along the lines of this very distinction that this chapter is structured. The justification for the specific models has been placed in the discussion of the 'second level'.

3.1 The Main Research

Since there are two research questions, this research can be divided into two distinct stages.

3.1.2 Constructing Causal Loop Diagrams

Stage 1 concerns Research Question 1: *To what extent can reconstructing Complex Adaptive Systems with Causal Loop Diagrams contribute to research in Development Studies?* As has been mentioned above, the main approach is of a learning-by-doing nature. The answer will be constructed inductively. It follows the following steps:

1. A Case Study as an Approximation of a Complex System
To analyse a real-life CAS is a very tedious task. Especially when it concerns a social system made up of humans, it is arguably impossible to study satisfactorily within the allotted six months. Therefore, in order to still being able to study such a system, a case study was selected. To increase the feasibility of this method, I will use the research results of Demmer & Overman (2001) as though they describe reality. Thus, my result will not necessarily simulate the actual behaviour of a community and its members, but the behaviour of that community and its members as depicted by the authors of the case study[2].

2. *Restructure the Case Study*
The relevant data has been distilled from the case study, summarised and grouped. Subsequently, CLDs were created to represent this data.

3. *Testing the CLD*
The CLDs were tested by a) checking every loop for logical consistency; and b) by checking the impact of interventions on the dynamics. The finalised CLDs are presented in Chapter 5 and validated along the same manner.

4. Induction
The merits of CLDs when applied to the case study are translated into general implications, thus to the extent to which CLDs might be useful for Development Studies as a discipline (i.e. to answer the first Sub Question).

[2] For the motivation for selecting this specific case study: see section 3.1.3. For an extensive coverage of the case study: see chapter 4.

3.1.2 Agent-Based Models

Stage 2 concerns Research Question 2: *To what extent can analysing Complex Adaptive Systems with Agent-Based Models contribute to research in Development Studies?* The answer will be constructed by considering applications of ABMs and by proposing a design for an ABM based on the CLDs.

3.1.3. Selection Case Study

The models are applied to the reality as constructed in this case study:

Demmer, J. & Overman, H. (2001) *Indigenous People Conserving the Rain Forest? The Effect of Wealth and Markets on the Economic Behaviour of Tawahka Amerindians in Honduras*. Wageningen: Tropenbos International. (Tropenbos Series; 19).

This case study has been selected, because it:

- concerns an indigenous community, which is a perfect case example of a CAS. Moreover, such communities are genuine units of analysis within Development Studies;
- concerns a small local community with few ties to the outside world. As such, it allows for grasping its internal dynamics without omitting relevant external factors. Actually, it is even a more suitable case study when considering the fact that the most significant disturbance from outside, namely the external market, is an independent variable introduced in their research
- explicitly deals with the interaction of a community and their environment, which allows for a more holistic approach towards the CAS;
- exhibits complex interaction between the agents and their environment;
- reports extensive data based on both quantitative and qualitative findings, which is most helpful when reconstructing Complexity, especially when considering that doing so was not at all the original intention of the authors;
- constitutes a representative instance of research carried out within Development Studies, and Sustainable Development in particular;
- The research topic is related to my personal research endeavours on Sumatra in the first year of my Master program; and,
- Professor Annelies Zoomers of the IDS department at Utrecht University has been one of the supervisors for this research project.

3.2 Models

This section is concerned with the models that are being scrutinised.

3.2.1 The Modelling Cycle

> The art of model-building is the exclusion of real but irrelevant parts of the problem, and entails hazards for the builder and the reader. The builder may leave out something genuinely relevant; the reader, armed with too sophisticated an experimental probe or too accurate a computation, may take literally a schematized model whose main aim is to be a demonstration of possibility (Anderson, 1977, pp. 381-382).

To perfect this art, it is necessary to carry out modelling in a structured manner. Railsback & Grimm (2012) contend that modelling scientifically entails the repeated iteration through the different task

of modelling several times. In order to elucidate this process, they have formulated the modelling cycle (see figure 3). Iteration then occurs by going through the whole cycle, or a smaller loop.

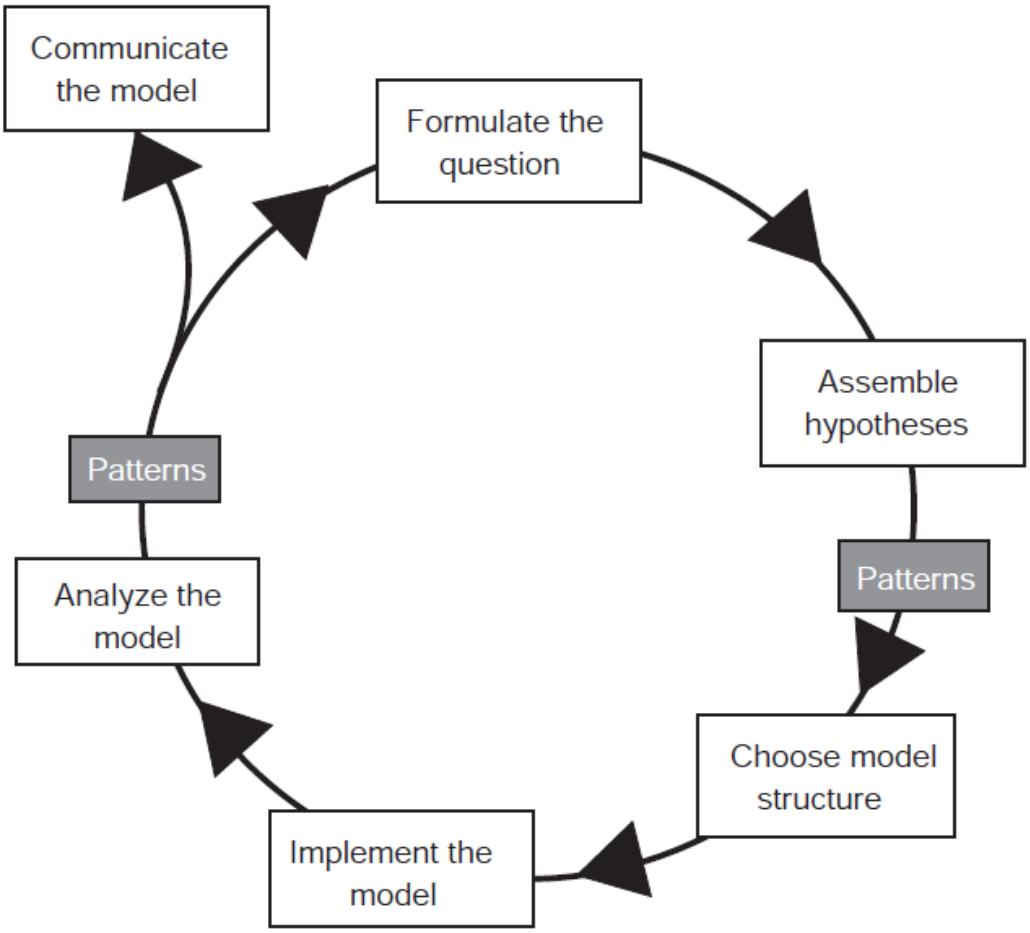

Figure 3.1: The Modeling Cycle (Railsback & Grimm, 2012, p. 7)

Because this research[3] is based on an actual case study, it is possible to go through this cycle more rapidly. Formulating the question and assembling the hypothesis can be skipped entirely in this case. Nonetheless, it is important to realise that when models would be built from scratch, based on real-life data, these linkages urge a constant act of reflection and refinement. That is also the reason why modelling, as a tool of analysis requires different types of data to be collected from the field, this will be discussed more thoroughly in the discussion of the results. The model structure can be captured quite well with a CLD as it is a powerful tool to visually convey the most important dynamics present in a system. After the formulation of a CLD, it becomes possible to implement the model, which is the most technical aspect. Therefore, due to the skewed time-investment necessary to master this skill, this part of the modelling cycle has been omitted with regard to the case study. Nevertheless, some recommendations regarding this aspect are presented at the end of this chapter. The analysis of the model is a very important aspect. In this study, the analysis will be carried out unidirectional (i.e. the data provided by case studies feed the analysis). In actual research efforts that include modelling, it is crucial for the (preliminary) analysis to take place alongside the collection of data. In this manner, it is immediately possible to yield field data that might have been deemed irrelevant before rendering the model. After all, it is the function of the model to grasp Complexity in a way that is hard or even impossible by other means, so it is only logical to assume that certain aspects of the system

[3] Please note that we are currently operating at the second level.

increasingly appear to be of vital importance. Again an aspect in which a CLD performs very well, since it is relatively easy to construct and does not necessitate many numerical values. This, however, will become clearer in the next section. Altaweel et al. (2010) recognise the usefulness of the modelling cycle because such a systematic approach assists communication between project members and also with the broader research community.

At this point, it might be enlightening to differentiate between the concepts of model and simulation. As stated before, a model is a set of mathematical representation of a system with as little detail as possible. A simulation, however, represents the operation of that system over time. Therefore a good simulation should include as much details as possible (Boccara, 2010). The main function of CLDs is representing models, while ABMs allow for a simulation, hence their description as simulation models. Although ABMs have much more capabilities, the strength of CLDs is clearly their relative simplicity. In conjunction, they can constitute an adequate instrument of dealing with Complexity: CLDs in the early stages of the modelling cycle; ABMs in the final stages.

3.2.2 Causal Loop Diagram

> As change-makers we should not try to design a better world. We should make better feedback loops (Barder, 2010, p. 15).

CLDs stem from System Dynamics. This type of diagram is grounded in four fundamental ideas:

1. The *structure* of a system, that is, the way its elements are inter-connected in cause-effect relationships, is key to explain the system's behaviour patterns.
2. *Feedback loops*.
3. In social systems (i.e. CAS'), *human decisions* play an important role in feedback processes. In System Dynamics, an accurate representation of how human beings perceive and act often plays a more important role in explaining behaviour patterns than 'hard data'.
4. Feedback processes do not operate instantaneously; the timing of behaviour depends on the presence of system elements that create *inertia* or *delays*.

(Richardson - made more concise by the author, 2005 p. 100)

In order to construct a CLD, Ford (1999) offers useful advice:

- Determine the most important variables in your system and represent them by variables in the CLD;
- The cause-and-effect connections in the real world can be represented by interconnections in the CLD.
- Again, keep the most important interactions, and leave out those that are irrelevant.

To make this more concrete, a very simple CLD is provided below (see figure 3.2).

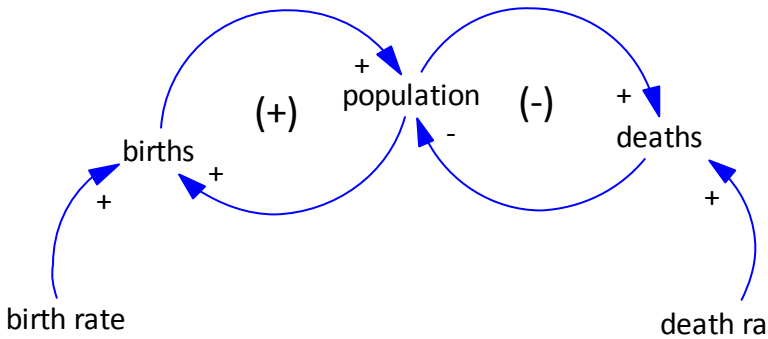

Figure 3.2: CLD of population dynamics (adapted version made in Vensim, based on Ford(1999)).

Figure 3.2 shows a CLD that illustrate Population dynamics. The plus signs on the arrow designate a positive relationship. So when for instance the value of a variable at one side of the arrow increases, the value of the variable at the other side of the arrow increases too. The loop on the left side is marked by a plus-symbol due to the fact that the entire cycle represents a positive relationship. To illustrate its working, let us consider the following example:

- When the population size increases, the amount of children born increases as well;
- When the amount of children born increases, the population size increases too.

The birth rate is not subject to feedback, but it is still an important element in this process. Again the positive sign means a positive relationship: a higher birth rate, causes more children being born.

On the right side, we can discern some minus signs. These designate negative, or inverse, relationships. Let us now consider the right side as an example:

- When the population size increases, the amount of people dying increases as well;
- However, when more people die, the population decreases again.

This mechanism is the reason why there is not limitless exponential growth of people on Earth: although the left side causes the amount of people to grow, the right side functions as a balance or inhibiting factor. This CLD might be extremely simple, its explanatory power is already significant:

- The reason why the human population is currently subject to such enormous growth is caused by the fact that improved health care and hygiene have lowered the death rate, which causes the right side no longer to be in balance with the left side (i.e. the left side is now dominant, (Richardson, 2005)).
- The reason why the human population grows so rapidly is due to the fact that the growth is proportional to its base value (i.e. population size). This means that it grows exponentially, instead of linearly.

So, constructing such diagrams immediately yields valuable insights into the workings of any complex system, as feedback, emergence and nonlinearity are already explicitly dealt with in even this simple CLD. Therefore Lane & Husemann (2008) argue that CLDs offer a useful framework for interventions to steer loops in social systems. Also due the fact that they are so strong as a communicate tool, they even help in including actors in the modelling process. When the process concerns actors with opposing views, these might even be consolidated to the fact that it helps actors appreciate the sensitivity and Complexity of the situation they find themselves in (Low et al., 1999). Miller et al. (2010) have conducted research on the Galapagos (see chapter 6) and they argue that participatory modelling itself is because of the reasons above a promising area of research. It allows for the inclusion of indigenous knowledge in the research and it empowers the beneficiaries to shape decisions.

In order to verify CLDs, it is appropriate to use narrative-oriented and qualitative ways (Manson & O'Sullivan, 2006). As the examples above illustrate, when going through the story told by the loops, does it seem to align with your intuitive understanding and your knowledge base? When it does not, it can have two distinct implications:

- The CLD is incorrect;
- The CLD offers counterintuitive insight of processes that actually really occur in the fashion as described by the model and new knowledge has been generated.

A final advantage of using CLDs versus traditional methods is the fact that:

> [CLDs] are explicit about assumptions and how they interrelate. Any concept that can be clearly described in words can be incorporated in a computer model. Constructing a computer model forces clarification of ideas. Unclear and hidden assumptions are exposed so they may be examined and debated. (Forrester, 1995, p. 5)

3.2.3 Agent-Based Modelling

"ABMs rely on a bottom-up approach that begins by explicitly considering the components of a system (i.e. individual agents) and tries to understand how the system's properties emerge from the interactions among these components" (McLane et al., 2011, p. 1545). So it is the method of choice when "you know a lot about individuals … [and you want to] … leverage that knowledge into information about collective dynamics "(Shalizi, 2006, p. 37). Instead of an isolated economic agent that has a set of fixed preferences and is geared towards maximising utility, an ABM introduces both heterogeneity among the agents and interaction between the agents (Vries, 2010). An ABM not only copes more explicitly with complexity, but its bottom-up approach fits well with the current paradigm within Development Studies. Therefore multi-agent simulation offers a most welcome alternative to the more conventional single meta-actor (Jager et al., 2000). It also counters the argument of humans not abiding by a single set of rules. ABMs indeed no only offer heterogeneity among their agents, but also allow for learning. As such, the set of rules changes along with the experiences of the agent. This also offers an adequate method of dealing with instances where agents to not have perfect information, the traditional assumption which is practically never valid. These simulations can even be rendered to reproduce empirical data and observations, to create system distributions (Vries, 2010) or to verify one's model.

Isreal & Wolf-Branigin (2011) have determined that "social service evaluators increasingly perceive their services as complex adaptive systems (CASs), the methods for evaluating such systems remain primarily qualitative and metaphorical … Taking the next step involves application [ABM]" (p. 20). And also within SACS the use of ABMs is increasingly being taken up as a suitable modelling tool for dealing in an adequate and legitimate way with Complexity. With ABMs it is possible to discover 'leverage points' and to see which parameters are most sensitive to initial conditions (ibid.). When designing interventions, projects or programmes this offers is an interesting testing ground, with minimal adverse costs when it should fail. That is also the reason why Forrester has often compared modelling and running simulations of social systems with the accepted practice of flight simulators, while the risk for social systems – especially within Development Studies – might be even graver. Janssen & Ostrom (2006) also describe the usefulness of ABMs when applied to case-study analysis. ABMs offer a save instrument for finding out what patterns emerge as a consequence of the interactions between the different components and how the system reacts to different policy scenarios.

Currently, the most popular software for modelling ABMs within the social sciences is NetLogo. It can be downloaded freely from http://ccl.northwestern.edu/netlogo/ and is accompanied by comprehensive documentation, tutorials and an active user community. While NetLogo is appropriate for most non-specialised ABM-related research, the extent of its use is also caused by the fact that it is also the software that is most prone to smooth mastery in relation to the current availability of software packages (Railsback & Grimm, 2012; Israel & Wolf-Branigin, 2011; Miller et al, 2010; Nikolai & Madey, 2009).

4. Case Study

After having grasped the theoretical foundation and motivation for the research presented in this thesis, it is of relevance to become further acquainted with the details of the case study. Not only will this aid establishing increased intuitive understanding of the models soon to be presented, but it is already the first step in creating the context in which the system operates (or by which the system is even constituted). As such, most details of the models in the next chapter will be entirely derived from the information provided in this chapter. Please note, once more, that the body of knowledge is extracted from the work by Demmer and Overman (2001). Their description of the Tawahka is considered the situation under investigation, instead of the situation as it really was.

4.1 The Tawahka Indians

The case study is focussed on a group of indigenous Indians in Honduras, called the Tawahka Indians. Honduras shares borders with the Caribbean in the north, Nicaragua in the East, El Salvador in the South and Guatamala in the West. It is the largest country of Central America after Nicaragua. The United Nations (UN) Human Development Index, which includes indicators for health, education and income, currently ranks the country 121 out of 187 countries. According to the UN, this means that the country's level of development is placed well below that of the Latin American and Caribbean average. A trend which has continued unaltered from the time of research until now (UNDP, 2012). Although Honduras used to be practically completely covered with forests, currently only 46% is left. The actual rate fluctuates, but annual deforestation has remained significant: -2.38% between 1990 and 2000; -1.95% between 2000 and 2005 and -2.16% from 2005 to 2010 (FAO, 2012).

The Tawahka Indians are the smallest, most isolated indigenous group in Honduras, and the only indigenous group living in a tropical rainforest. Their population totals to less than 1,000 people and is distributed over five communities within a radius of 40 km. These communities are situated at the boundary between the flatland and the foothills, around the confluence of the Wampu with the Patuca river (see figure 4.1). Travel is only possible by use of the river, which might even be rendered impossible during severe dry seasons, which may take place around April and May. Consequentially most agricultural activity takes place along the river banks, as does extraction of larger forest products, which are uneasy or even impossible to transport otherwise. There is no seasonal inundation of the river banks and practically all land along the river between the Tawahka villages is populated by secondary vegetation as many Nicaraguan refugees utilised it to sustain their livelihood during the 1980s.

In 1987 the Tawahka founded the Federation of Indigenous Tawahka in Honduras. Their main accomplishment consists of attaining their very own reserve, called the Tawahka Asangni Biosphere Reserve. Yet institutional enforcement of environmental protection or recognition of indigenous rights is weak in the face of the ongoing stream of encroaching agricultural and cattle fronts and illegal logging operations. At the time of study, about 17,000 colonists lived within the confines of the reserve. Due to frontier expansion, the Pech, which used to be another rain-forest-dwelling indigenous group, is now largely integrated into the Honduran non-Indian (*Ladino*) society (Kolankiewicz (1989) in Demmer & Overman, 2001).

The area forms part of the Carribbean lowlands and the tropical climate there is generally hot and humid. The dry season only lasts two months, from March to April. The mean temperature is 27˚C and the lowest and highest temperature respectively 13˚C and 38˚C. During the years of research, precipitation amounted to 3,200 mm per annum.

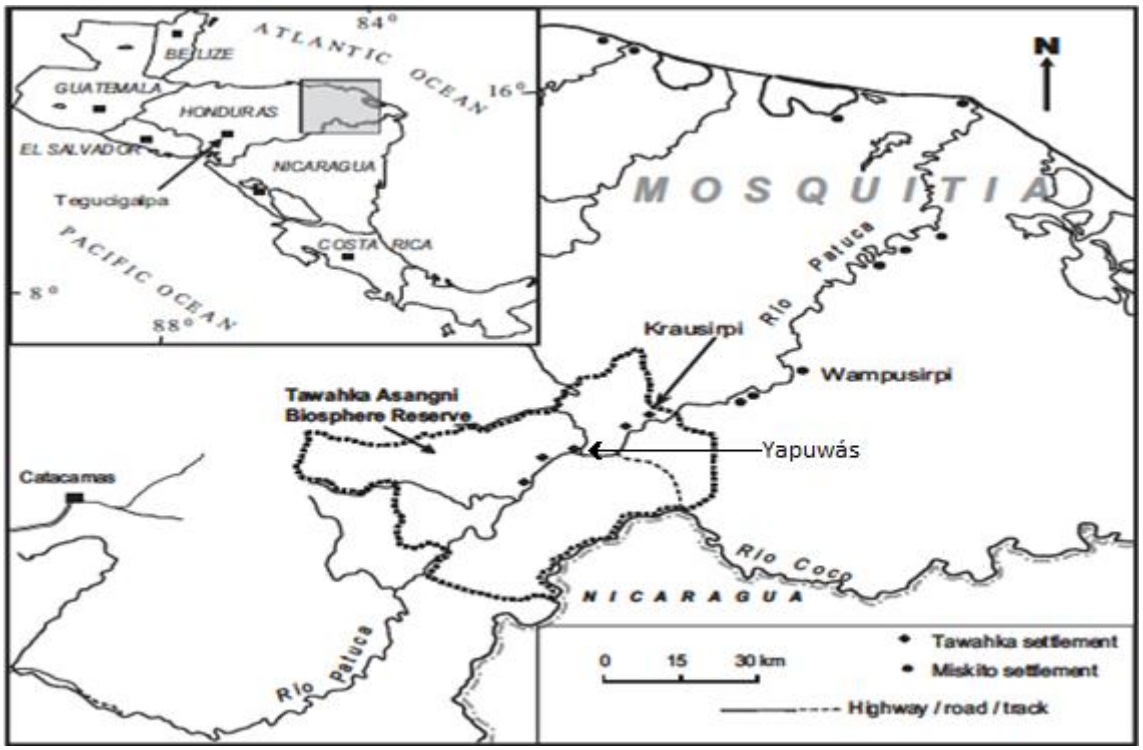

Figure 4: The Tawahka Asangni Biosphere Reserve (PNAS, 2003). Yapuwás marker added by the author.

4.2 History of the Tawahka Indians[4]

Only little is known about the early history of the Tawahka as the Spanish did not really venture there. There are, however, some missionary accounts originating from the 16th and 17th centuries. They describe the Tawahka to be living in small semi-permanent settlements. They mainly lived from food extracted from the forest and fishing, while additionally harvesting some sweet cassava and corn. The availability of essential forest products often urged the Tawahka to migrate.

The Tawahka had a primarily egalitarian social system. Councils of elders offered advice while at times shamans and military leaders assumed leadership. The latter was required to settle disputes as hostilities within and between neighbouring Indian communities were a continuous occurrence. As deadly vengeance was a common response to crimes. The Tawahka did not practice any institutionalised form of religion; any religious act was based on animism and shamanism instead. It is only due to the recent establishments of Catholic churches that urged the Tawahka to practice Catholicism. It is, however, mainly a way to behave in a modern fashion.

When the English appeared, the Tawahka had little incentive to engage in extensive trade or labour contracts as they believed their communities to provide them in all their needs, except for the occasional axe or shotgun which they did indeed find useful. Wealth was certainly not an end in itself.

From linguistic information it is known that the Tawahka are related to the Sumu Indians of northeastern Nicaragua, from which they were separated due to Miskito hostilities. The English prompted the Miskitos to engage the Tawahka more peacefully and as a consequence, many intermarriages with the Tawahka took place. Also a fair share of Tawahka have Paya or Ladino ancestors and, indeed, few 'pure' Tawahka remain, to such an extent that Tawahka men generally even speak Miskito among themselves. Women, however, do speak the Tawahka language with one another. Spanish is spoken as a third language to enable communication with people from the

[4] For a more extensive historical overview, please consult the following literature on which Demmer and Overman rely almost exclusively: Consemius, 1932; von Houwald, 1980; Newson, 1986 & Roberts 1827.

outside world. Nonetheless, many elders and most women do not have the required language proficiency to do so.

4.3 Contact with the Outside World

Apart from some sporadic historic encounters, the 1980s marked the turning point regarding contact with the market. During the Sandinista-Contra war in Nicaragua a massive number of Amerindian refugees settled in the area. Some intermarriage occurred, but most returned to their homeland afterwards. However, the Tawahka communities had been noticed and religious missions and the NGO MOPAWI which operated in Wampusirpe and coastal towns until the mid-1980s, became part of the life of the Tawahka. MOPWAI initiated some small-scale development projects and introduced hybrid cacao.

The largest Tawahka village, Krausirpe, has been, and still is, mainly oriented towards Wampusirpe. The other communities are in turn oriented towards Krausirpe. Wampusirpe has a supply of industrial products from the coast city Ahuas and also has the facilities to place orders by radio from greater cities in Honduras, such as the second largest city of Hunduras San Pedro Sula. Nevertheless, most trade in the smaller Tawahka communities also sparked in the 1980s when increasing numbers of river traders passed their habitat. During the time the research took place, the first Tawahka were reported to make trips to the outside world by themselves to supply their store and export small amounts of crops.

The Tawahka also cherish the tradition for young men to venture into the non-Tawahka, yet still proximate, world to gain experience and possibly find a future wife. Women, however, barely ever travel beyond the Tawahka villages.

4.4 Livelihood Strategies

The Tawahka have various ways of sustaining their livelihood. Here a brief overview is provided of all their strategies. According to Demmer and Overman they can be best characterised as subsistence farmers, growing a variety of bananas and plantains, sweet cassava, beans, rice and some small amounts of corn. Aside from farming, they hunt animals, fish and gather wild fruits from the forest. Additionally, the forest provides them with practically all necessary construction materials for either building houses or canoes, medicines, dyes and other useful items.

Currently the Tawahka economy is semi-monetised. Since links with the outside world have increased, a number of modern industrial products have become part of the daily essentials, such as cooking oil and salt. To acquire these, cash is mainly earned by engaging in wage labour for Ladino bosses: gold panning far upriver, labouring on farms or clearing forest land. Additional cash income is derived from selling animals or part of the harvest. Since the 1990s, cacao is increasingly grown as a cash crop and some Tawahka have become more specialised and sell canoes to outsiders, run a shop, sell handicrafts, teach, guide tourists through the forest, transport people or even engage in agricultural work for fellow Tawahka's. Food from the forest is also increasingly being substituted by agricultural products.

Men usually work in the morning and in the afternoon they mainly rest or do small chores in and around the house. In the largest Tawahka village Krausirpe, men often work longer hours and stop around 5 PM. Women already start before dawn and are responsible for the largest share of the household activities. At times, especially when the men are away from home, they go fishing with hook and line. They, however, never go to the forest to either hunt or gather there. It is male territory exclusively. Women also sometimes assist men during agricultural activities, by sowing or harvesting. Because there is no electricity in the Tawahka communities, people only work during daylight hours.

4.5 Impact on the Environment

Demmer and Overman (2001) have found that increased integration into the market leads to various impacts on the forest. The amount of products extracted from the forest on the household level seems to correlate positively with increased market integration. Supposedly this is caused by the fact that newly acquired technology such as rifles and saws make it more lucrative to extract products from the forest. However, when integration further increases, other livelihood strategies seem to lead to a higher yield, while simultaneously the consumption of forest products is being substituted by agricultural and industrial products. Thus, the rate of extraction from the forest is seen to decline when the integration within the market increases.

The stress on the forest is further increased by the fact that integration into the market also leads to a more extensive reliance on agriculture. This necessitates the clearance of more forest area. Tawahka engage in a variety of types of wage labour. Some of these are most detrimental to the forest, such as clearing the forest for expanding colonists and cutting high value trees for a canoe construction. These activities, often by nature, correlate with increased integration into the market.

4.6 The Methodology of Demmer & Overman

Two teams composed of two researchers each spent two and a half years consecutively from mid-1994 onwards in two Tawahka villages: Krausirpe and Yapuwas . Their research was focussed on the following research questions:

Research Question:
To what extent does indigenous rain forest resource use change with increasing levels of wealth and integration into the market?

Sub Question 1:
How do different levels of wealth affect labour investments, leisure consumption rates and sources and amounts of cash earnings among households?

Sub Question 2:
To what extent do trade links with the outside world alter the economic behaviour of indigenous households?

Sub Question 3:
How does the total use of forest resources change with increasing household wealth and integration into the markets?

Sub Question 4:
Are there marked differences in Tawahka economic behaviour as a result of seasonal rhythms, and what are the roles of the forest and wealth as safety nets during lean periods?

Sub Question 5:
What are the consequences of increased household wealth and integration into the market for animal and plant populations in the surrounding rainforest?

Unit of analysis
Demmer and Overman (2001) have selected the household as the unit of analysis as they have found that households as a whole can be seen as a single “co-operating unit that decides about production, on when to hunt, how much forest to cut for agriculture, on material investments, etc. In other words, the unit which determines the intensity of interaction with its surroundings ... and not an

individual person, family or entire village." (p. 104). The definition of household that they used was "a group of people who regularly eat from the same stove" (ibid.) as this coincides with the definition of the Tawahka themselves and is, as such, deemed most appropriate for inquiry.

Their research is based on a sample size of 33 households out of a total of 68 households, thus representing 49% of the entire population in both villages under investigation and 29% of the entire Tawahka population in Honduras which consists of 115 households.

Definitions

They used four indices to measure *forest resource*: 1) time investment; 2) consumption; 3) cash income; and, 4) area under cultivation. *Economic wealth* was measured by the depreciated value of a household's assets. *Integration into the market* has been defined as: 1) the degree to which a household is exposed to 'foreign' goods or has opportunities for trade with outside markets; 2) the actual level of incorporation of external trade, foreign trade, foreign goods and behaviour into an individual's life. The level of integration into the market is based on the amount of cash income that it had generated through transactions with outsiders or with a village store. *Outsiders* were defined as any non-indigenous person or non-local indigenous person.

Research sites

The research sites consist of two of the five villages. The most important characteristics of these are shortly discussed here. Krausirpe is the village closest to the market town of Wampusirpe, around 32 km as the crow flies and also the most modern of all five Tawahka villages. About half of all the the Tawahka live in Krausirpe, which is 53 households and around 479 individual inhabitants. It has active NGOs, a primary school, a small government health clinic, church and retail stores. The other village, Yapuwas, although just 22 km upriver from Krausirpe, has none of all those fancy facilities; although a school started there a few years before the researcher were there, as was a bamboo church build there during their stay. In Yapuwas there are 14 households and around 99 inhabitants. Although there seems to be great variation in integration level across these villages; there is likewise great variation within the villages.

Note of interest

Not long after the research was finished, Hurricane Mitch roamed across the Tawahka lands in October 1998 which has severely disrupted the lives of the Tawahka. Although all Tawahka were warned in advance and all survived, some of their villages were completely covered by mud and almost all cacao plantations were destroyed. Wong & Godoy (2003) have carried out research in the villages after this event, yet their findings are beyond the scope of this research.

5. Creating a Causal Loop Diagram

In this chapter the results of the first research question are presented:

To what extent can Causal Loop Diagrams help dealing with Complexity in Development Studies?

As has been elaborated upon in the previous methodological chapter, this will be done in an inductive fashion. First a couple of CLDs will be constructed to gain increased understanding of the impact of market integration on livelihood strategies of the Tawahka. Second, a CLD will be presented that goes into more detail regarding what impact market integration has on forest use. Finally, the last section will be briefly summarise the findings to give general recommendations to elucidate to what extent CLDs can be of use within the discipline of Development Studies.

5.1 Impact of market integration on the livelihood strategies of the Tawahka

Since the CLDs in this chapter are derived from data from the case study, CLDs are constructed as follows:

1. Relevant findings from the case study are presented (which are discussed in more detail in chapter 4);
2. Tables are formulated that contain the rules/strategies extracted from these findings;
3. These tables are finally put together in a single CLD.

Section 5.2.1 is devoted to the creation of a CLD that represents the livelihood strategies of the Tawahka before they were integrated into the market. Then the subsequent section is concerned with the manner in which their strategies have been altered due to integration into the market.

5.1.1 Livelihood strategies before exposure to the market

Relevant information from the case study

Traditionally, the Tawahka Indians in Honduras:

- "mainly [lived] from food gathered in the forest, hunting and fishing. They moved frequently in response to the availability of wild plantains . . . and other forest products" (Demmer and Overman, 2001, p. 92);
- "practiced some agriculture with sweet cassava . . . and corn" (ibid.);
- relied exclusively on the forest for construction materials to build houses and canoes, medicines, dyes and other necessities;
- "lived in small semi-permanent settlements" (ibid.).

This study, however, is not concerned with the way the Tawahka way of life changed since their first contact with the outside world. Rather, the focus is on exposure to the market and the consequential semi-monetisation of the Tawahka economy. Therefore the decades up to the 1980s are regarded as the period representing the pre-market situation.

Prior to market integration, the Tawahka Indians in Honduras:

A. "[were] mainly subsistence farmers, growing several varieties of bananas, sweet cassava, beans, upland rice and some corn" (ibid., p. 95) and they kept a very small amount of domesticated animals (i.e. chickens, pigs and cows);

B. completed their dietary needs by hunting, fishing and foraging;
C. relied exclusively on the forest for construction materials to build houses and canoes, medicines, dyes and other necessities;
Z. lived in five permanent settlements.

Excerpt 'Z' has been added to illustrate that the Tawahka already had a permanent settlement before their economy started to be monetised. Section 3.2 seems to suggest that this has been caused by developments in the wider Honduran context. So when the model wishes to explain the traditional situation too, it is necessary to include and explain the mechanisms behind this process. This would, however, unnecessarily complicate matters further and would obscure the main focus of this chapter (i.e. illustrate the usefulness of system dynamics). Moreover, any details regarding this development are also beyond the scope of the research of Demmer and Overman.

Table with all the relevant information

The information above fits neatly into the following table.

EXCERPT	STRATEGY	GENERAL STRATEGY	GOAL
A	Grow variety of bananas	Work in agriculture	Meet demand for agricultural products
A	Grow sweet cassava		
A	Grow beans		
A	Grow rice		
A	Grow corn		
A	Keep domesticated animals		
B	Hunt animals	Hunt/gather in the forest.	Meet demand for forest food
B	Fish		
B	Gather wild fruits		
C	Extract materials for house	Extract materials from the forest.	Meet demand for materials
C	Extract materials for canoe		
C	Extract medicines		
C	Extract dyes		
C	Extract other		

Table 5.1: Livelihood strategies before exposure to the market.

The table above is structured as follows:
1. The column with the heading 'EXCERPT' refers to the excerpt of information derived from the case study in order to aid transparency;
2. 'STRATEGY' concerns the specific type of livelihood strategy employed by the Tawahka households;
3. 'GENERAL STRATEGY' allows for bundling individual strategies together. This has two advantages:
    a) to avoid clutter in the final model; and
    b) to make in an explicit link with the category in the fourth column.
4. 'GOAL' describes the motivation for engaging in a (general) type of livelihood strategy.

An example:
The Tawahka hunt animals. This belongs to the general strategy of hunting and gathering in the forest. The goal of hunting animals (and hunting and gathering in general) is to meet the household

demand for (forest) food. This specific livelihood strategy is described in excerpt B of the previous section.

A first CLD

With table 5.1 it is possible to construct figure 5.1. In figure 5.1, however, there are a couple of new elements that have not been included in table 5.1, nor has it been subject of the research by Demmer and Overman. To elaborate on this issue, this section will discuss how all the different elements are related to each other, or in other words: what all the arrows signify. Relations will only be discussed thoroughly when they are not deemed counterintuitive or necessitate proof. To increase clarity, instead of categories of products (e.g. agricultural produce), in this section specific products (e.g. beans) are the subject of investigation. This will allow for a more intuitive understanding of the dynamics under consideration and offers a proper introduction of how the diagrams could be applied to enhance understanding of specific trends within a system.

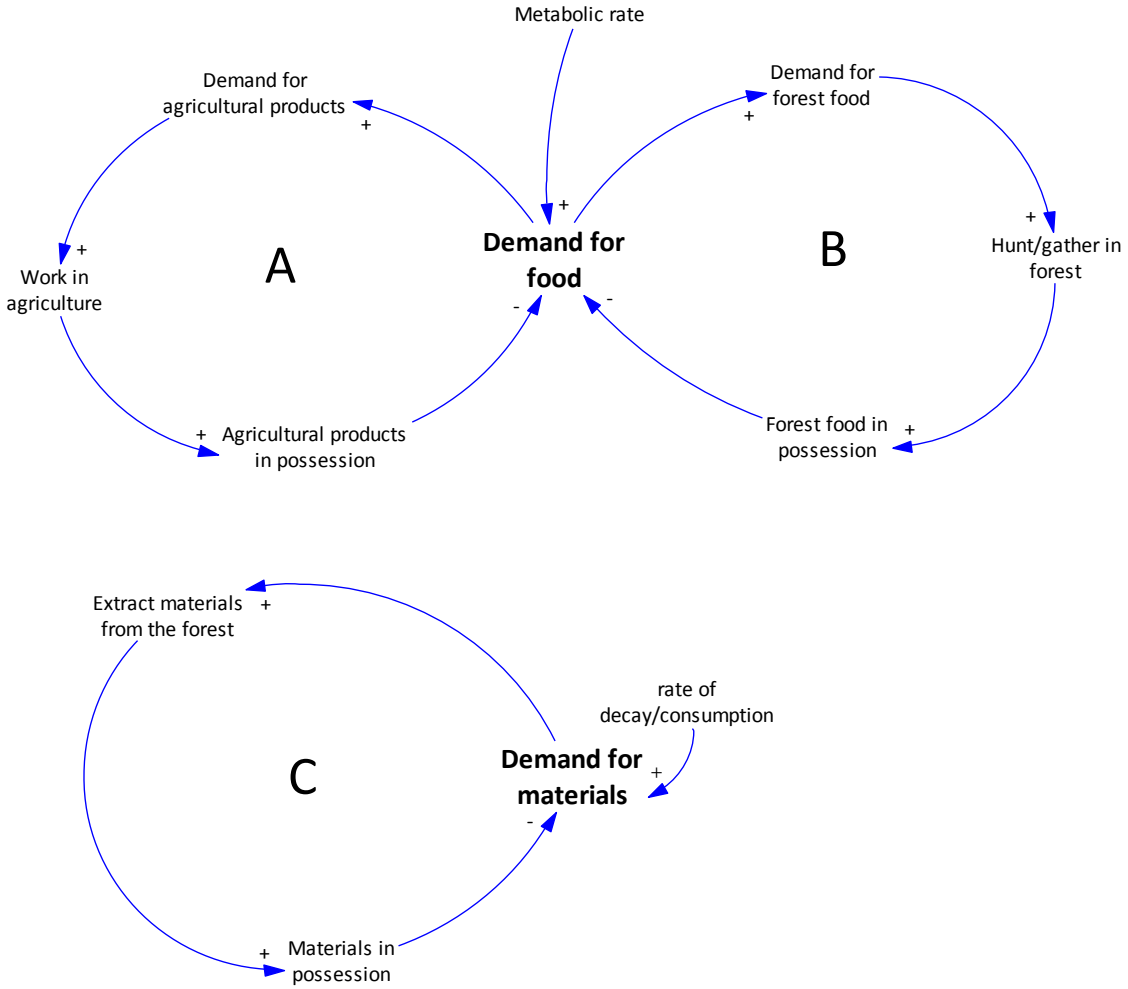

Figure 5.1: CLD of livelihood strategies before exposure to the market. The capital letters in the loops indicate to which excerpt they refer.

Loop A represents the livelihood strategy of Tawahka households as subsistence farmers. If we instantiate agricultural produce with beans, ignoring substitute agricultural products, the loop can be explained as follows:

- When the demand for food increases[5], the demand for beans increases;
- When the demand for beans increases, the household has to grow more beans;
- When the household grows more beans, it harvests more beans and consequentially has more beans in possession;
- When the household has more beans in possession, the demand for food decreases.

Loop B represents the reliance on the forest for food. In this case, forest food will be replaced by hunting animals:

- When the demand for food increases, the demand for game meat increases;
- When the demand for game meat increases, the household hunts more in the forest;
- When the household hunts more in the forest, it has more game in possession;
- When the household has more game meat in possession, the demand for food decreases.

Loop A and B together constitute the manner in which Tawahka households meet their demand for food. In the explanation above, both loops seem to be stabilizing, because after any food-generating activity the demand decreases. The reason why this cycle repeats itself daily is because of the last relation in this system that has been left untouched so far: the metabolic rate. Due to the fact that all members of the household require a minimum amount of food at any time interval, it becomes necessary to continuously go through this cycle.

Loop C represents the reliance on the forest for materials. In this case, materials will be narrowed down to materials necessary for constructing a house:

- When the demand for construction materials increases, the household extracts more of these materials from the forest;
- When the household extracts more construction materials from the forest, it has more construction materials in possession;
- When the household has more construction materials in possession, the demand for construction materials decreases.

Similar to the system above, the demand for materials is a stabilising demand. The only reason why construction materials are being necessary (besides household expansion – which is the focus of section 5.4), is because of the fact that materials are subject to decay or need to be replenished.

Now a model has been constructed of the livelihood strategies of the Tawahka before market integration, it is time to consider a model that includes exposure to the market.

5.1.2 Livelihood strategies after exposure to the market

Relevant information from the case study

After market integration, the Tawahka Indians in Honduras:

A. “are mainly subsistence farmers, growing several varieties of bananas, sweet cassava, beans, upland rice and some corn” (ibid., p. 95) and they keep a very small amount of domesticated animals (i.e. chickens, pigs and cows) both for meat and dairy products;
B. completed their dietary needs by hunting, fishing and foraging;
C. rely heavily on the forest for construction materials to build houses and canoes, medicines, dyes and other necessities;

[5] Please note that the increase in this example could also be replaced by a ‘decrease’, yielding the exact opposite result.

D. have a semi-monetised economy. “Cash, needed to obtain essential goods such as salt, cooking oil and soap, is acquired by seasonal gold panning far upriver, labouring on *Ladino* farms nearby[,] selling an animal or portion of the crop[,] growing cash crops such as cacao, selling canoes to outsiders, running a shop, selling handicrafts, teaching, occasional tourist guiding, transporting people or doing agricultural work for other Tawahka” (ibid., pp. 95-96);
Y. are all exposed to the market as market presence is a village level variable. “Market participation, on the other hand, refers to the actual level of incorporation of external trade, foreign goods and behaviour into an individual’s life ... [In the case study] the term ‘integration into the market’ [indicates] the links with the outside world … [A] household’s level of integration into the market [is based] on the amount of cash income that it had generated through transactions with outsiders or with a village store” (ibid., p. 109);
Z. live in five permanent settlements.

Besides the addition of dairy products and a decreased reliance on dairy products, the livelihood strategies based on excerpts A, B and C have not been altered. Nevertheless, the addition of excerpt D does have profound consequences on the way of life of the Tawahka.
Although most details in excerpt Y are already touched upon in section 4.5, it remains important to bear in mind what is meant by market integration, as it eventually explicitly needs to be added to the model in order to understand the transition from the pre-market to the present situation. Market integration will then function in a similar manner as ‘metabolic rate’ and ‘material decay/consumption’ in figure 5.1.

Table with all the relevant information

Again, the information above fits neatly into table 5.2. While most of the pre-market system is still intact, the newly introduced livelihood strategies do make Tawahka life (or at the very least a model of Tawahka life) more complex. This is due to the fact that a demand for industrial products cannot be met by simply creating or extracting it from the local environment. Instead, cash is required in order to trade the desirable products. So a demand for industrial products instantaneously leads to a demand for cash money. To acquire this money, the Tawahka either sell the surplus from activities in which they already used to be engaged in (i.e. intensification) or they engaged in new types of economic behaviour (i.e. diversification). Demmer and Overman posit that this eventually even leads to specialisation.

A second CLD: industrial products

As stated above, the basic dynamics of A, B and C have been left unaltered. Nonetheless, there are some important observations that can be made in advance when considering figure 5.2.
The first observation concerns the fact that now system A, B and C are all connected to each other. Because of the introduction of cash, the economy has started to become monetised and this entails that suddenly livelihood strategies can be seen as specialised activities that might be employed to obtain cash; instead of retaining just the old function of simply acquiring the product it yields for own use. As will become apparent below, the new type of system favours activities that yield more cash, while discouraging activities that are less likely to yield cash.

EXCERPT	STRATEGY	GENERAL STRATEGY	GOAL
A	Grow variety of bananas	Work in agriculture	Meet demand for agricultural products
A	Grow sweet cassava		
A	Grow beans		
A	Grow rice		
A	Grow corn		
A	Keep domesticated animals		
A	***Extract dairy products***		
B	Hunt animals	Hunt/gather in the forest.	Meet demand for forest food
B	Fish		
B	Gather wild fruits		
C	Extract materials for house	Extract materials from the forest.	Meet demand for materials
C	Extract materials for canoe		
C	Extract medicines		
C	Extract dyes		
C	Extract other		
D	***Pan gold***	***Wage labour***	***Meet demand for industrial products***
D	***Labour on Ladino farms***	***Wage labour***	
D	***Sell wild animal from forest***	***Sell forest food***[6]	
D	***Sell portion of the crop***	***Sell agricultural products***	
D	***Grow cacao***	***Sell agricultural products***	
D	***Sell canoes to outsiders***	***Sell forest material***	
D	***Run a shop***	***Sell industrial products***	
D	***Sell handicrafts***	***Sell forest material***	
D	***Teach at a local school***	***Wage labour***	
D	***Guide tourists***	***Wage labour***	
D	***Transport people***	***Wage labour***	
D	***Agricultural labour for other Tawahka***	***Wage labour***	

Table 5.2: Livelihood strategies after exposure to the market. Newly introduced strategies are displayed in bold and italic for representational purposes.

Secondly, this new system has come about as a consequence of the introduction of a foreign trader; or in other words, due to introduction to the market. It is interesting to observe that when market integration increases, and the Tawahka engage in more trade, they become agents of market integration themselves, thus even furthering this development.
Let us consider the diagram more closely in the same manner as above to offer a firmer grab of the new processes that now take occur. By themselves, loop A, B and C show the same behaviour as in figure 5.1. Now, however, there are new linkages to the broader system. To understand the new situation, it is most illustrative to depart from loop D.

[6] Although it is best placed within the category of forest food (i.e. selling is the substitute for the traditional consumption and these animals are practically never sought specifically for but only incidentally found when being in the forest for other activities), the animal is often sold for other purposes, such as being an exotic pet or for its fashionable or medicinal properties.

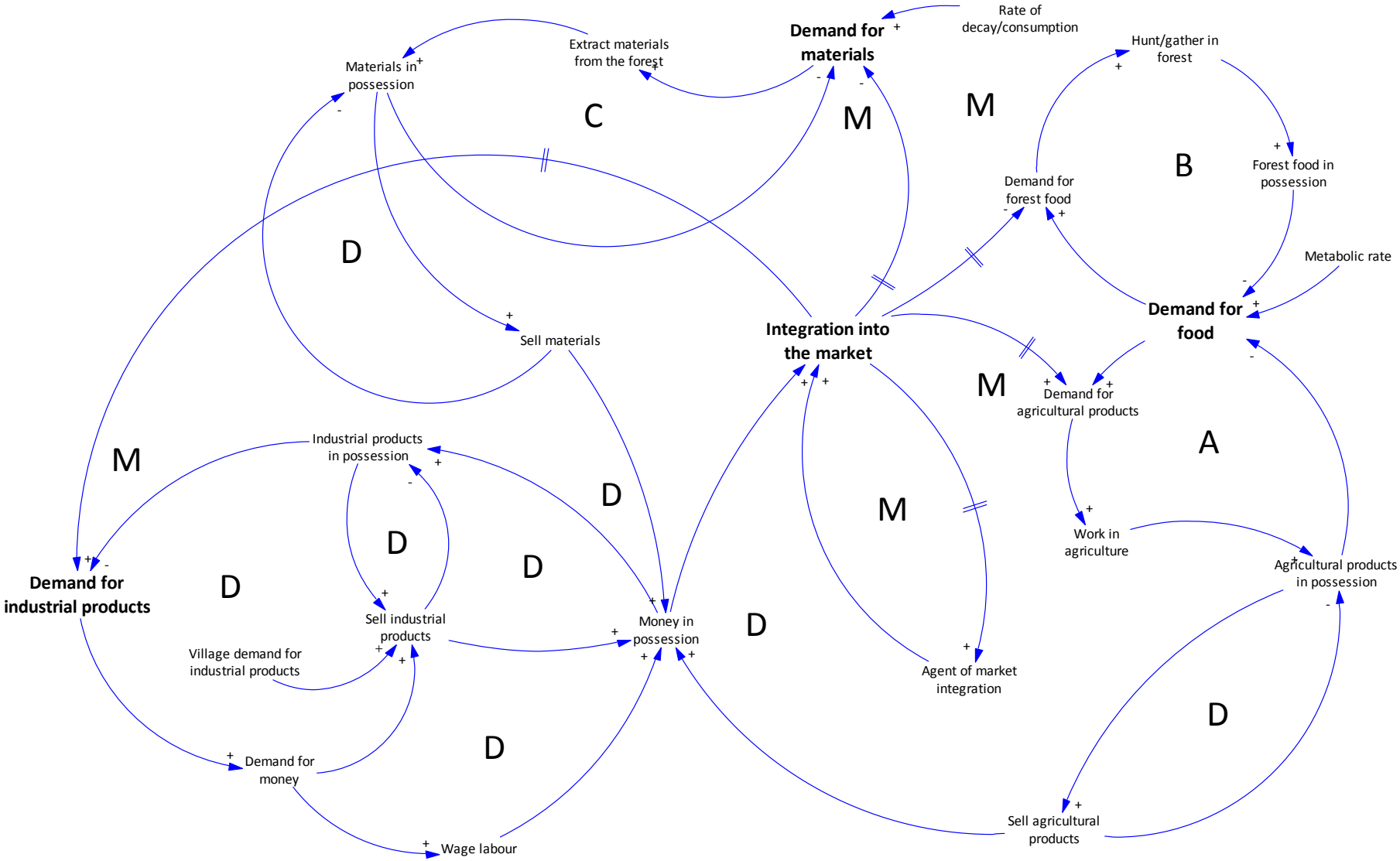

Figure 5.2: CLD of livelihood strategies after exposure to the market. The capital letters ‘A’,’B’,’C’ and ‘D’ in the loops indicate to which excerpt they refer. The ‘M’ refers to the loops that are caused by integration into the market.

The examples will still revolves around beans, hunting animals and materials for constructing a house. Industrial products will be instantiated by salt. In later examples we will delve more deeply in instances where industrial products are actually substitutes of other types of products, but for now, this simplification will hold just fine. As can already be noticed at first sight, a substantial amount of new loops are introduced in this second diagram. In order to avoid repetition, not every individual loop is discussed separately, but every type of strategy will be. Going through these examples is an important aspect of testing the diagram. Even without having comprehensive knowledge of the system under investigation, its internal logic can be tested vis-à-vis intuitive understanding. And, of course, sometimes it is counterintuitive and yet completely valid. In these instances CLDs can contribute greatly to generate new knowledge. In these examples, however, this will not be the case.

Example 1 represents the mechanism of households engaging in wage labour in order to fulfil their demand of salt (and takes place within the D-oval in the left section of figure 5.2):

- When the demand for salt increases, the demand for money (i.e. cash) increases;
- When the demand for money increases, the time the household spends in wage labour increases;
- When the household spends more time in wage labour increases, it has more money in possession;
- When the household has more money in possession, it can have more salt in possession (due to increased purchasing power);
- When the household has more salt in possession, the demand for salt decreases.

This example already illustrates that because the 'demand for money' has become explicit, the acquisition of money becomes an end in itself. This becomes even more apparent in example 2.

Example 2 represents the mechanism of households picking up trade in order to acquire more money (and takes place in the upper rights side of the D-oval in the left section of figure 5.2):

- When the household has more money in possession, it can have more salt in possession;
- When the household has more salt in possession, it can sell more salt to other households;
- When the household sells more salt to other households, it has more money in possession.

Acquiring money has thus become a viable livelihood strategy by itself, too. While initially only value was generated by obtaining products from the environment, suddenly trade has become an interesting activity too, very interesting actually as we observe in this example the first positive loop so far. While the Tawahka are used to call it a day as soon as they acquired all the desired products, opening a local shop offers them the opportunity to increase their wealth exponentially.

As all significant processes have to become explicit in a model, it is appropriate to shift our focus to the reason why the livelihood strategies of the Tawahka have altered in the first place: integration into the market! All loops associated to this variable have been granted the 'M' for market. Let us consider some examples revolving around this 'M'. In contrast with the foci above, market integration will not be subject to instantiation.

Example 3 represents the intimate relation of use of industrial products and integration into the market. This example is actually a variation of the loop described in example 1, and as such, situated at the same location in figure 5.2; but with a tendency towards the center.

- When the demand for salt increases, the demand for money (i.e. cash) increases;
- When the demand for money increases, the time the household spends in wage labour increases;
- When the household spends more time in wage labour increases, it has more money in possession;

- When the household has more money in possession, it is increasingly integrated in the market[7];
- When the household is increasingly integrated in the market, its demand of salt increases.

As this last relationship concerns a change in general lifestyle, figure 5.2 shows a delay. Upon closer investigation, it becomes apparent that all outgoing arrows of 'Integration into the market' is subject to a delay. This is because behavioural changes do not occur overnight. The following example elucidates this more strikingly.

Example 4 represents the manner in which households themselves increase the integration into the market of other households (and takes place within the centre of figure 5.2):

- When the household is increasingly integrated in the market, it increasingly becomes an agent of market integration;
- When the household increasingly becomes an agent of market integration, it (and other households) increasingly integrate into the market.

Households mimic each other's behaviour, open a shop within their village or make a habit of consuming certain industrial products, they integrate into the market even more. So, again, we have found an important positive loop.

Thus, untill now, our CLDs have already allowed us to explain why the introduction of an (external) agent of market integration:

- The Tawahka economy becomes increasingly (exponentially!) monetized;
- The Tawahka villages become increasingly (exponentially!) integrated into the market.

This is a most noteworthy finding as Demmer & Overman do not explain these phenomena in their work, but only state that they occur.

5.2 Impact of the livelihood strategies on the forest

Demmer and Overman (2001) ultimately wish to investigate how the altered pattern of livelihood strategies impacts the forest. In table 5.3 the four activities that impact the forest are expressed, along with their corresponding relation to integration within the market. The variables in the column on the left are identical to their counterparts in figure 5.3. Due to communicative purposes, however, the rest of the clutter has been omitted.

Activity	**Relation with market integration**	**Relation with the condition of the forest**
Hunt/gather in forest	Negative	Negative
Extract materials	Negative	Negative
Work in agriculture	Positive	Negative
Wage labour in the forest	Positive	Negative

Table 5.3: The impact of livelihood strategies on the forest condition.

This table, again, can be directly translated to a causal loop diagram below (see figure 5.7).

[7] Please recall that Demmer & Overman base the level of a household's integration into the market on the amount of cash income that it had generated through transactions with outsiders or with a village store (section 4.5).

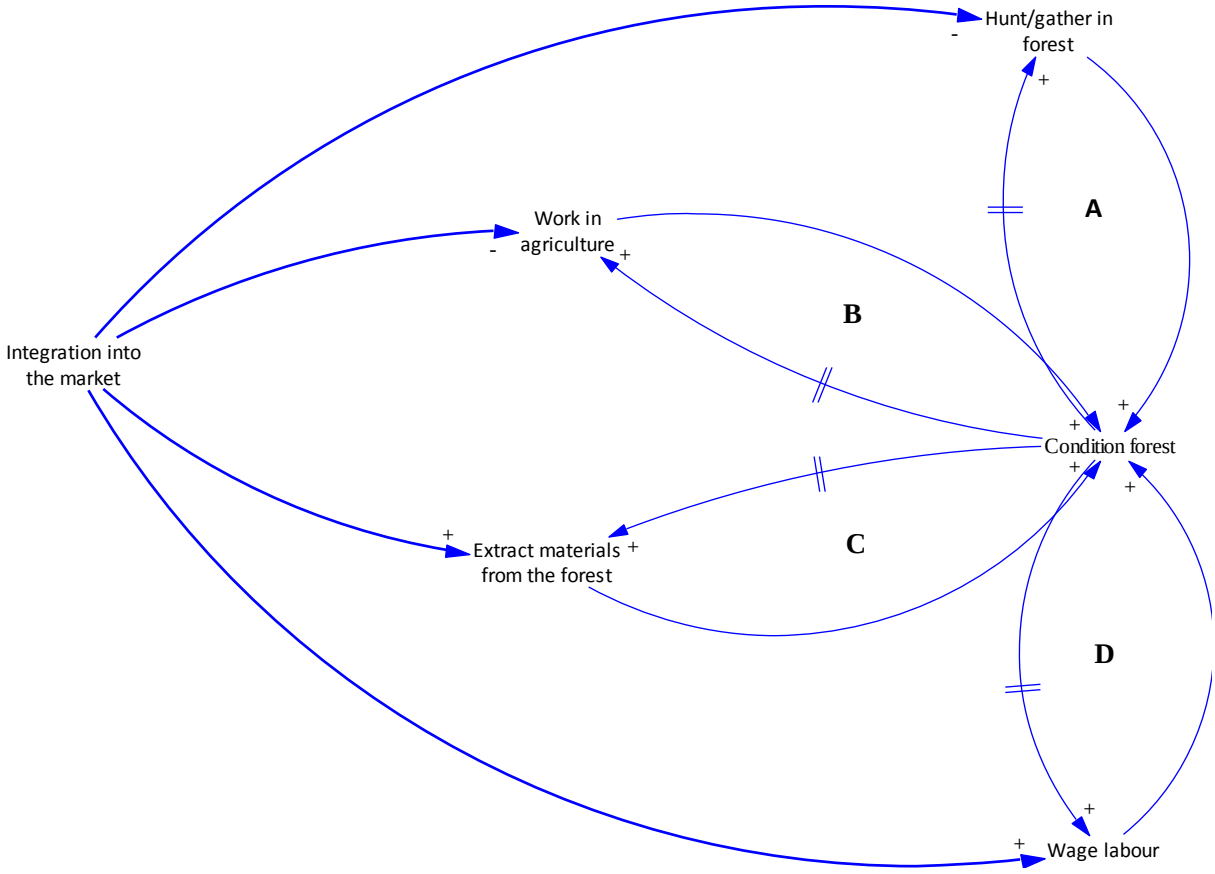

Figure 5.3: CLD of the (indirect) effect of integration into the market on the forest condition. 'A', 'B', 'C' and 'D' loosely correspond to the loops with the same designation in figure 5.2.

Figure 5.3 illustrates that the negative feedback loops would automatically halt the overexploitation of the forest. However, the delays imply, as with all common pool resources, that the feedback loop from the forest on the own productivity will be felt much later than when it has been impacted. As a consequence, the forest might have already deteriorated significantly before the forest has deterred any adverse use.

So, when considering the loops in this diagram, the following conclusions can be drawn regarding increased integration into the market:

a) The condition of the forest improves in so far that hunting and gathering decreases;
b) The condition of the forest deteriorates as agricultural expansion increases;
c) The condition of the forest improves in so far that the extraction of forest materials decreases; and,
d) The condition of the forest deteriorates in so far that Tawahka Indians have the opportunity to earn cash income by clearing the forest for agricultural purposes or for instance by engaging in wage labour for a commercial canoe constructor.

In this instance, the CLD in figure 5.3 by itself seems to offer barely more explanation as table 5.3.

This is, however, not the case. Figure 5.3 is most useful because:

- It can be combined with the CLD in figure 5.3 to allow for understanding complex cause-and-effect relationships, effectively allowing for combining the different results of the sub questions of Demmer and Overman to give a true definite answer to their broad research question (albeit in the shape of a diagram);

- It prompts researchers to make the value of relationships explicit. If we would know the extent of forest degradation related to every forest activity, this would already allow for an answer that is more clear-cut;
- As has been concluded from the CLD in figure 5.2, increased monetisation of the economy and increased integration into the market of households, prompts increased (possibly even exponential) activity. Thus, this entails that the extent to which the forest is used, will increase.
- If more data relevant for the construction of a model would have been acquired[8], it becomes possible to see whether for instance agricultural expansion can continue even more aggressively when the condition of the forest seems to become of decreased importance due to the decline of traditional uses of the forest.

In the next section the findings above are generalised in order to answer the first sub question.

5.3 General Implications

The implications can be subdivided into two different categories, namely the analytical implications (i.e. to what extent do CLDs contribute?) and the requirements for applying CLDs (i.e. what are the preconditions for working with CLDs and how does this relate to the modelling cycle?).

5.3.1 Analytical Implications

- Conform the expectations (see chapter 3), CLDs takes explicit account of the main concepts of Complexity. The concepts are well-integrated in the model and certain complex characteristics become automatically discernible when creating CLDs;
- CLDs are a nice alternative to narratives as systems can be compared on the basis of their structure;
- It is easy to observe what the effect of an intervention will be as one can simply add a new variable to a loop and reason what will happen;
- When a system exhibits behaviour that is not conform a CLD this either means that other variables need to be taken in too (thus informing the data collection process) or that certain loops are dominant (which could hint at a tipping point);
- Indirect relations that usually require a wordy contextual analysis become easily observable; as for instance the complex relationship of integration into the market with the condition of the forest;
- CLDs allow for combining the different sub questions in order to offer a holistic answer to the main research question;
- CLDs do not require much expert knowledge and could be widely applied within Development Studies. Moreover, its capabilities as a communicative tool even allow for participatory approaches;
- As CLDs require a lot less data than other modelling techniques, it is a most useful tool for informing data collection process;

[8] Which would occur in any research adhering to the modelling cycle elaborated on in chapter 3.

- CLDs ensure a holistic picture of system under investigation as every relation has to become explicit and a gap quickly becomes apparent.

5.3.2 Requirements

- Basic knowledge of System Dynamics;
- As CLDs consists of causal loops is important to make the direction of relations explicit. Currently, many relations are mainly identified as being either significant or not significant, but the causal link is not made explicit. The advantage of CLDs is the fact that the relationships described do not require a specific value, so occasionally using intuition will be sufficient. Nonetheless, the reliability of a CLD is substantially enhanced when this causality could be made explicit;
- Every relation that is deemed necessary for recreating a system with a CLD should be subject to investigation, in order to bolster the CLD.

6. Agent-Based Modelling

In this chapter agent-based models are discussed more thoroughly in order to gain more insight with relation to the second research question. This will complement the literature reviews above by illustrating more tangible applications of ABMs. The model presented in the first section is a rather simplistic model in order to get acquainted with the workings and potential of ABMs. The second chapter will be of a more practical nature and proposes an ABM based on the CLDs in the previous chapter.

6.1 The AIDS Model

This section is structured in such a manner that the implications of the ABM should become apparent to neophytes is well. Therefore it is possible to see along screenshots of the ABM in Netlogo in what manner the model develops. This model can be found in the Model Library[9] and it is also possible to run the model in an internet browser[10].

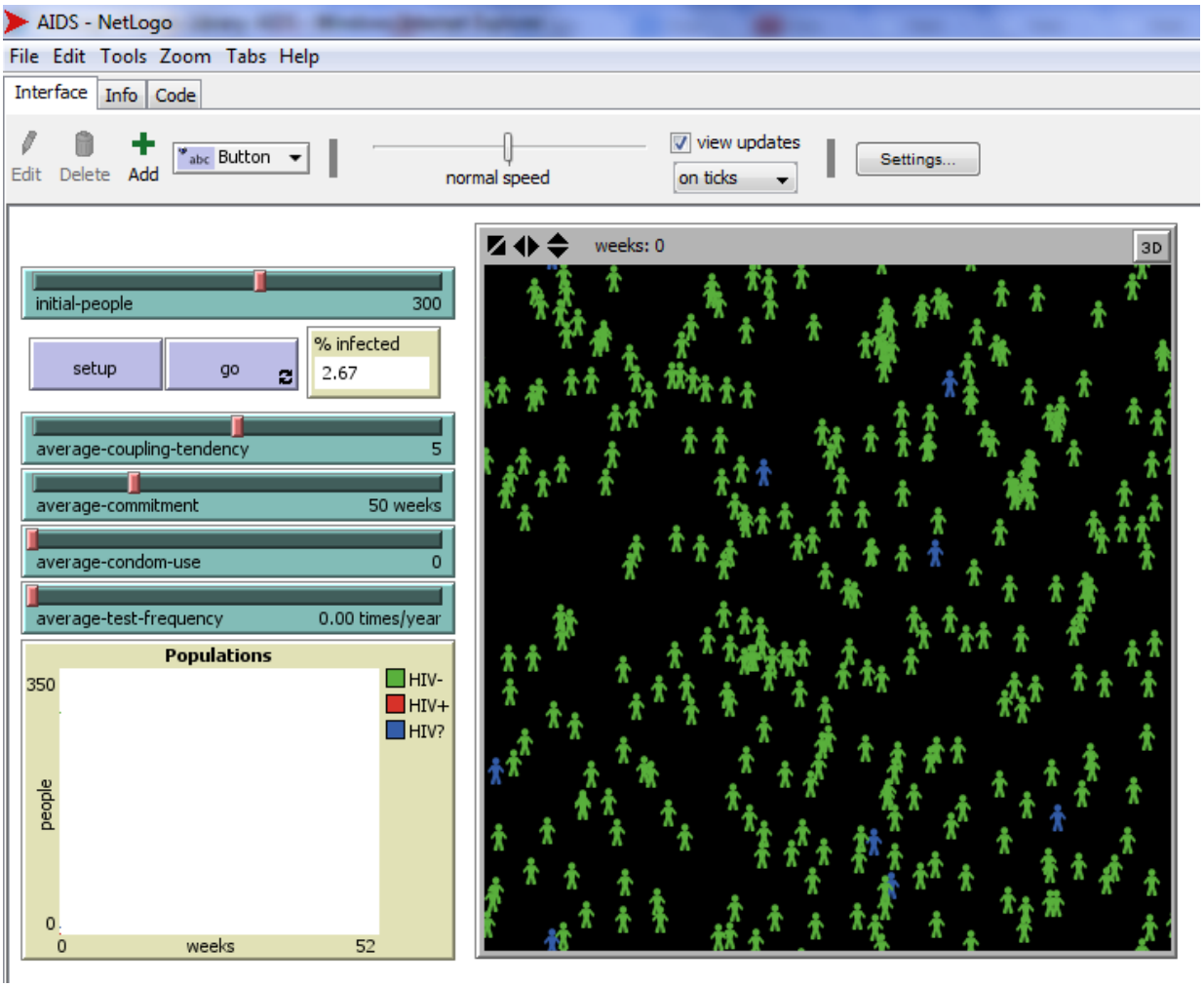

Figure 6.1: Screenshot of a setup of the AIDS model in Netlogo

[9] It can be located by clicking on 'File' in the upper left corner and following the following path: File/Models Library/Social Science/AIDS

[10] It can be found at the following URL: http://ccl.northwestern.edu/netlogo/models/AIDS

6.1.1 Description

Although the model is called AIDS it simulates the spread of HIV in an isolated human population. Within this model, HIV spreads as a consequence of sexual interactions exclusively. The spread is counteracted by abstinence, the amount of time being together with a single partner, the tendency to use condoms and the tendency to get tested for HIV. The latter is important as in both reality as in the model, it takes a considerable amount of time before the symptoms of HIV become apparent. It is assumed that people knowing of their ill condition practice only safe sex.

6.1.2 Translation

This brief description can be translated to the ABM as depicted in figure 6.1 & figure 6.2 as follows:

- The agents are human beings, represented by blue en green people, or 'turtles' in the NetLogo jargon;
- Green people are healthy, blue people are HIV-positive but are as of yet unaware of that fact and red people are HIV-positive and they aware of their condition;
- People move around randomly, thus randomly influencing other people with a determined probability of having sex;
- The counteracting forces described above, can be manually altered before or during the simulation. This function can be found at the left side of the display[11]. For instance, in figure 6.1 the average relational commitment to a specific partner is set at 50 weeks. Note that it states the average commitment. In this specific model this tendency differs per individual and is defined by a use of a normal distribution;
- To communicate the amount of people infected over time, a plot has been included on the bottom left.

6.1.3 Representation

The model starts with a setup (see figure 6.1) based on the setting 'initial-people' and places the people in random locations. The user can run and pause the model by using the 'go' button. In NetLogo time is simulated by 'ticks', which entail that at each tick all agents perform an action and a new situation arises. In this particular model, each tick represents a week (see the upper part of the display in figure 6.1 or figure 6.2). In figure 6.2 it is possible to witness the situation after 1017 weeks. If we take the plot on the bottom left into consideration, we can see that the amount of HIV-positive people used to grow steadily, but after a while exploded, quickly granting the group of red people dominance over the system.

6.1.4 Implications

This simple ABM illustrates that ABMs in NetLogo indeed provides Development Studies with a most useful tool to deal with Complexity. The three most important findings are:

- Through local interactions of people, the emergence of patterns can be simulated in a nonlinear fashion;
- Heterogeneity among agents can be introduced and this can contribute to learning (in this case ironically depicted by spreading HIV);
- The effects of interventions can be modelled in a straightforward manner. In this model, this could for instance be done by simply introducing or by increasing tests for HIV. The nonlinear

[11] NetLogo offers full freedom to modellers regarding which options they wish to grant users.

implications of this model are depicted in Figure 6.3 and it becomes apparent that at the time[12] most people were HIV-positive in the first model, a tendency to test once every three years has stabilised the amount of HIV-positive people.

The research conducted by Miller et al. (2010) is an interesting example of testing interventions by means of ABMs.

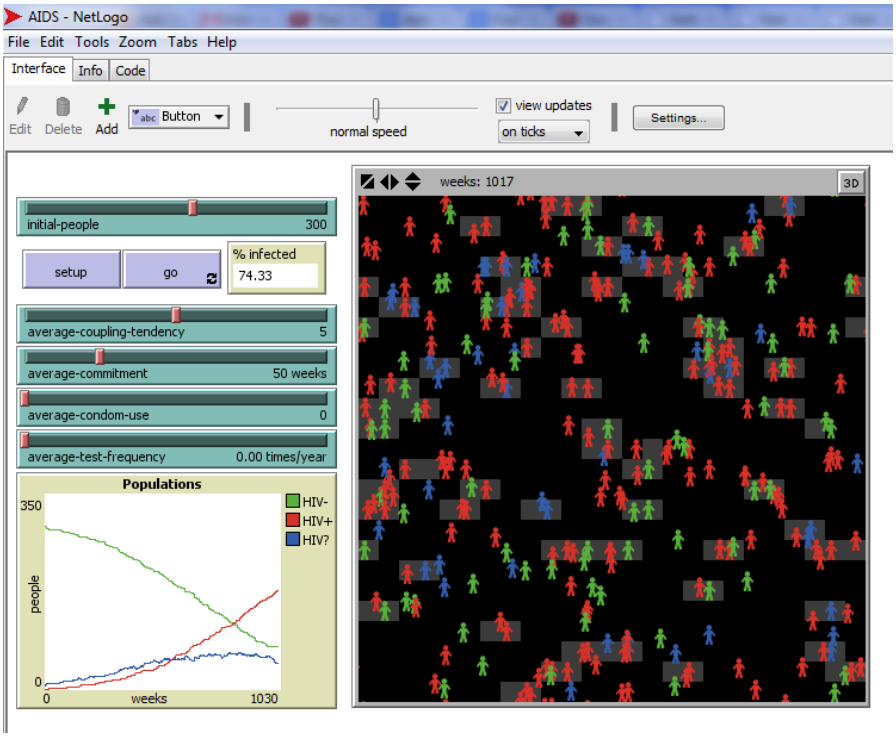

Figure 6.2: Screenshot of a state of the AIDS model in Netlogo

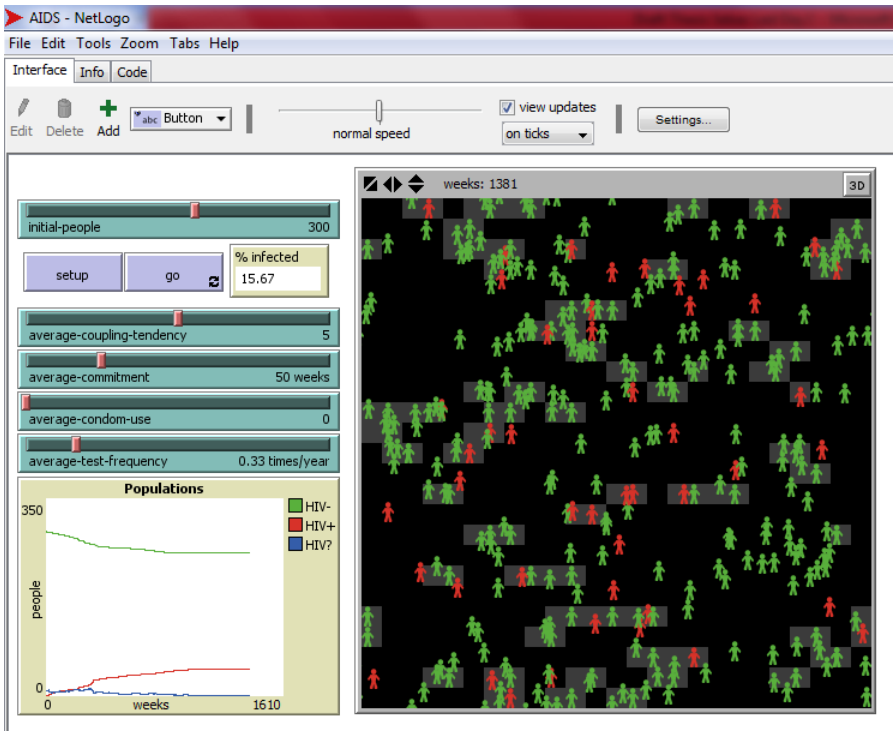

Figure 6.3: Screenshot of a state of the AIDS model in Netlogo with testing set at 33%

[12] Please not that figure 6.3 proceeds over a longer time span (i.e. 1381 weeks) than figure 6.2 (i.e. 1017 weeks)

6.2 A Tawahka Model

The merits of ABMs have been stressed throughout this research. With the addition of a description of the AIDS model above, it is possible to grasp what ABMs have to offer to the already significant contribution of CLDs towards grasping Complexity. In this section an ABM will be proposed based on the Tawahka case study described above. The construction of an adequate ABM is beyond the scope of this paper, due to the following reasons:

- Too little specific information is available to run meaningful model that actually allows for the generation of additional knowledge (i.e. the value/strength of many relations is unknown);
- To model the ABM will all its relevant aspects, significant mastery of a software package such as NetLogo is required.

6.2.1 Description

The proposed model revolves around the manner in which livelihood strategies are affected by integration into the market. The main unit of analysis, similar to the research of Demmer & Overman, is the Tawahka household. Every household has a distinct set of livelihood strategies and consumption patterns which are prone to change over time. Households can interact with each other. Interactions might consist of learning or trading. Learning allows agents to change each other's internal representation; while trading allows agents to change each other's levels of possession as well. Livelihood strategies affect the physical environment.

6.2.2 Translation

- Households are represented by agents (turtles);
- Each agent has an internal variable keeping track of its integration into the market. For visual purposes, each degree of market integration can correspond to a certain shade of colour;
- Each agent has its own set of livelihood strategies;
- The degree of market integration influences the probability of employing a set of livelihood strategies;
- A set of livelihood strategies determines the probability of an agent pursuing a certain livelihood strategy;
- Each tick an agent pursues a certain livelihood strategy determined by the probability of each strategy;
- The degree of market integration determines the probability of having a certain consumption pattern
- Each agent has an internal variable keeping track of its possession;
- Possessions influence the probability of pursuing certain livelihood strategies;
- Each tick an agent consumes some of its possession, which is determined by the agent's consumption pattern;
- Each tick there is a certain probability agents meet each other;
- When agents meet, there is a probability learning and/or trading occur(s);
- Learning influences the behaviour of both agents engaged in this activity;
- Trading influences both the behaviour as the possessions of the agents involved;
- Livelihood strategies determine the levels of environmental stocks;
- Environmental stocks influence livelihood strategies;

- At the Setup of the model, one, or a few agents are introduced into the model that have a high level of integration into the market, this is the external;
- Without the introduction of this trader, the Tawahka system should be balanced.

6.2.3 Representation

- Each tick an agent moves to certain locations to illustrate in which activity it is engaged;
- Different shades of colour illustrate the agent's degree of integration into the market;
- Plots illustrate the most interesting relationship;
- Sliders allow for the manipulation of all the variables mentioned above.

6.2.4 Implications

An implemented version of the Tawahka model would finally give a definite answer to the main research question, namely to what extent use of the forest changes as a consequence of integration into the market and increased wealth.

This hypothetical endeavour has also illustrated that CLDs are an appropriate means for identifying the most relevant aspects of a CAS that are necessary for the input of an ABM.

7. Conclusion

This research has focussed on two research questions, the first one being:

To what extent can reconstructing Complex Adaptive Systems with Causal Loop Diagrams contribute to research in Development Studies?

Throughout this research it has become clear that it is indeed possible to construct CLDs of CAS that are the subject of research conducted in Development Studies. While the authors of the case study had to rely heavily on quantitative measures to describe the villages of the Tawahka, the CLDs seem to capture the same dynamics within a single model. CLDs indeed require a narrative for it to work, so it functions well as a supplement to existing research practices. This would allow for checking for complex dynamics that had not become apparent through other techniques. Additionally, hypothetical situations and interventions can be evaluated within the context of the entire system, instead of investigating its effect per variable and basing a decision on summing up pros and cons. As has been shown in the previous chapter, CLDs are also an appropriate stepping stone for more advantaged modelling techniques such as ABM.

The true strength of a CLD, however, arises when it is applied within earlier stages of research, conform the modelling cycle. When CLDs are constructed beforehand and updated throughout the research, they can inform the collection of data. Moreover, this also allows for verifying whether preconceived notions are valid in reality. If unforeseen processes seem to arise in the field, this means that there are different causal loops at work than originally envisaged.

Another advantage of CLDs is their strength to compare patterns in different systems. Comparing any complex social system to each other of course always relies on reductionist principles, but CLDs at least base their comparison on interaction between elements, instead of individual elements.

The downside of CLDs can be found in the fact that they require the collection of data that has not been deemed necessary for the application of other methods within Development Studies. A notable example is the reliance of CLDs on explicit knowledge about the causal direction of relationships. Often these causalities can be inferred or are simply common sense, yet occasionally it will require a substantial investment on the part of data collectors. As argued before, however, obstacles should never be the issue; how we can apply new insights, should be.

Research Question II:
To what extent can Agent-Based Models contribute to analysing Complex Adaptive Systems within Development Studies?

ABMs have proven to match well with the current paradigms in Development Studies. Current research endeavours that include ABMs seem to have yielded promising results. The problem, however, lies in the fact that ABMs require substantial modelling knowledge. While it takes only little effort to understand them and appreciate their use, it requires significant skill to engage in true scientific research. This should not deter any researcher who wishes to use them though. Interdisciplinary efforts that include at least one modelling expert should already be sufficient to work cooperatively on ABMs as their workings are quite simple to grasp.

The future of ABMs is therefore most likely to be determined by pioneers who take this effort and present other scholars the usefulness of these models. Currently, across all disciplines, the amount of ABM users continues to grow. Let us hope Development Studies follows suit soon, and tip Complexity in our favour.

8. Limitations & Future Research

Hereby a brief overview of recommendations related to follow-up research is provided.

8.1 CLDs

This research has argued that CLDs are a very useful tool for capturing Complexity and especially in the field of Development Studies due to their representational merits. System Dynamics has thus proven itself to be a useful discipline for dealing with complex issues. To rely even more heavily on its merits, one can also consider employing stock & flow diagrams as tools of analysis. This will prove to be of particular use when research deals with stocks and flows, as is for instance the case when investigating the dynamics of human interaction vis-à-vis resources bases. Moreover, another important use of these diagrams might be testing the validity of CLDs as they are easily transformed in one another. To illustrate this, let us revisit the example of population dynamics presented in chapter 3.

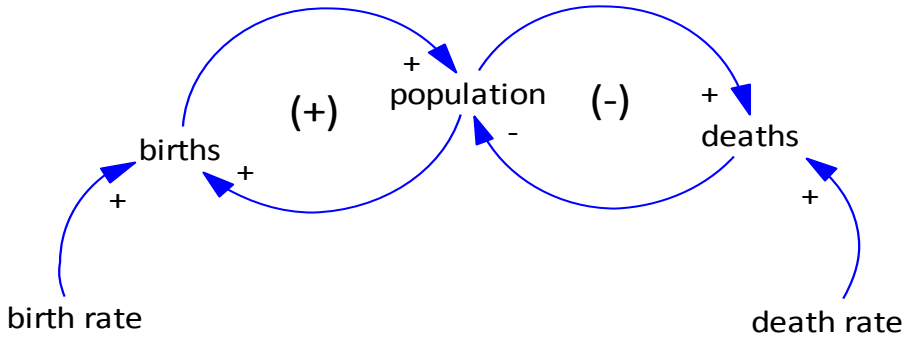

Figure 8.3: CLD of population dynamics (based on Ford(1999))

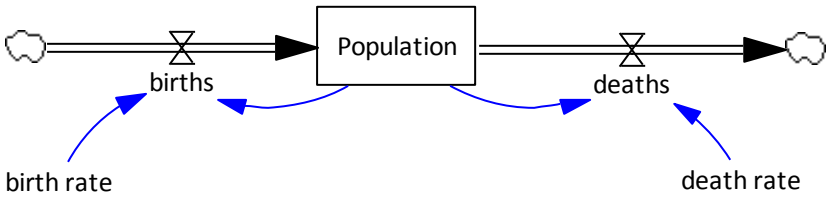

Figure 8.2: Stock-Flow Diagram of population dynamics (based on Ford(1999))

While figure R.2 appears similar, and is to a certain extent similarly constructed, its use differs by means of enabling the modeller to insert numerical values for any variable. Thus it is possible to provide an explicit output when one does know the values of the input. Although I argue that CLDs are sufficiently useful for representing Complexity within Development Studies and that a proper next step should be the application of ABMs (due to the nature of the discipline, focussing more on people and their internal representation than actual stocks), it is an application that might prove very useful in specific types of research falling within the scope of Development Studies.

8.2 ABMs

This research has argued for integrating ABMs into the palette of tools of analysis for Development Studies. The following four types of future research could strengthen this argument and make it even more tangible:

Map as many related research endeavours in other disciplines. Although I have already examined many of the most likely candidates, the diversity of disciplines active in this field necessitates a specific research doing just so. The Journal of Artificial Societies and Social Simulation, the discipline of SACS and especially the ABM by Miller et al. (2010) will proof a proper point of departure;

Examine which methodologies currently applied within Development Studies should be replaced by techniques that have the power to deal more adequately with nonlinearity.

Model actual research with NetLogo (or any other suitable software package). One should take the modelling cycle, so the collection of data should be informed by the (early) stages of implementation. To work with ABMs it is useful to follow a special ABM protocol. The two most commonly applied are the Overview, Design Concepts, Details (ODD) protocol by Grimm and others and MR POTATOHEAD (Altaweel, 2010 et al.). ODD is the most popular of the two and most attuned to NetLogo.

Another fruitful direction is related to the integration of ABMs and GIS (see for instance Brown et al. (2005)), which is applied more in research in which the spatial dimension has a more prominent role.

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