Drivers of violent property crime in South Africa: A system dynamics model focussing on education- and income inequality

by

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Abstract

Crime statistics released by the South African Police Service (SAPS) indicate that the total number of annually reported crimes decreased steadily between 2008 and 2019. However, annual reported robberies have been steadily increasing over the same period. This indicates that South Africa's crime prevention strategies are effectively reducing certain types of crime in the country. Robbery prevention strategies, however, still require further development.

This study therefore investigates drivers of robbery, where they form part of violent property crime, by means of a system dynamics methodology to aid the decision-making process for South African robbery prevention strategy development. This study is aligned with the aims of the 2030 National Development Plan (NDP) and conducted in the context of South African education- and income inequality.

A scoping literature review was conducted to gain perspective on mathematical models that had been developed by previous crime-related studies. The results of the review indicate a lack of literature concerned with rigorously validated system dynamics models studying robbery within the South African context.

Additionally, a conceptual literature review was conducted to identify drivers of robbery in South Africa, as well as criminological theory relating to these. The reviewed literature suggests that inequality, one of the sustaining factors of the South African culture of crime and violence, is arguably the core problem of violent crime in South Africa. Among other inequalities, income inequality, as measured by the Gini coefficient, has been shown to be especially high in South Africa. Literature investigating the causes of South Africa's high income-inequality suggests that unequal education levels among citizens is one of the major causes of income-inequality. Researchers seeking empirical evidence for criminological theories that advocate the relationship between inequality and crime have found some support for their hypotheses, but these relationships are generally weak. However, researchers who sought evidence for this relationship without considering the specific hypotheses of these criminological theories found stronger support, even in the South African context.

A dynamic hypothesis, in the form of a system dynamics simulation model was then developed from the arguments found through the conceptual review. The model focuses on relationships between education inequality, income inequality, incidents of robbery and a culture of crime and violence. These relationships are partially based on arguments of general strain theory, social learning theory, differential association theory and routine activity theory. The model was evaluated with validation tests and it was concluded that the model is appropriate for its intended purpose. Several scenarios aimed at reducing South African robbery through increased education levels, were then simulated by the model.

Overall, the simulation results suggest that a reduction of robbery incidents through improvement of South African education levels will require a long time to produce a significant effect. However, the results do suggest that such interventions also generate long-lasting effects which consequently would require a long time to reverse. Furthermore, the results indicate that combinations of interventions generate stronger effects than the sum of effects produced by interventions applied in isolation.

Opsomming

Misdaadstatistieke wat deur die Suid-Afrikaanse polisiediens (SAPD) bekend gemaak is, dui aan dat die totale aantal misdade wat jaarliks aangemeld word, tussen 2008 en 2019 geleidelik afgeneem het. Die jaarliks-aangemelde rooftogte het egter gedurende dieselfde tydperk geleidelik toegeneem. Dit dui aan dat Suid-Afrika se misdaadvoorkomingstrategieë sekere soorte misdaad in die land effektief verlaag. Roofvoorkomingstrategieë vereis egter nog verdere ontwikkeling.

Hierdie studie ondersoek dus met behulp van ’n stelseldinamika-metodiek die dryfvere van roof waar hulle deel vorm van gewelddadige eiendomsmisdade. Die doel daarvan is om die besluitnemingsproses vir die ontwikkeling van Suid-Afrikaanse roofvoorkomingstrategieë te verbeter. Hierdie studie is in lyn met die doelstellings van die 2030 Nasionale Ontwikkelingsplan (NOP) en is uitgevoer in die konteks van Suid-Afrikaanse opleiding- en inkomste-ongelykheid.

’n Verkennende literatuuroorsig is gedoen om perspektief te kry op wiskundige modelle wat deur vorige misdaadverwante studies ontwikkel is. Die resultate van die oorsig dui op ’n tekort aan literatuur wat handel oor streng geverifieerde stelseldinamika-modelle wat roof binne die Suid-Afrikaanse konteks bestudeer.

Daarbenewens is ’n konseptuele literatuuroorsig gedoen om sowel dryfvere van roof in Suid-Afrika as die kriminologiese teorie hieroor te identifiseer. Die hersiene literatuur dui daarop dat ongelykheid, een van die faktore wat die Suid-Afrikaanse kultuur van misdaad en geweld laat voortduur, waarskynlik die kernprobleem van geweldsmisdaad in Suid-Afrika is. Onder ander ongelykhede blyk dit dat die inkomste-ongelykheid, gemeet aan die Gini-koëffisiënt, veral hoog is in Suid-Afrika. Literatuur wat die oorsake van Suid-Afrika se hoë-inkomste-ongelykheid ondersoek, dui daarop dat ongelyke opleidingsvlakke onder burgers een van die belangrikste oorsake van inkomste-ongelykheid is. Navorsers wat empiriese bewyse vir kriminologiese teorieë soek wat die verband tussen ongelykheid en misdaad voorstaan, het ’n mate van steun vir hul hipoteses gevind, maar hierdie verwantskappe is oor die algemeen swak. Navorsers wat bewyse vir hierdie verwantskap gesoek het, en die spesifieke hipoteses van hierdie kriminologiese teorieë buite rekening gelaat het, het egter sterker steun gevind, selfs in die Suid-Afrikaanse konteks.

’n Dinamiese hipotese, in die vorm van ’n simulasiemodel vir stelseldinamika, is toe ontwikkel uit die argumente wat deur die konseptuele oorsig gevind is. Die model fokus op verhoudings tussen opleidingsongelykheid, inkomste-ongelykheid, voorvalle van roof en ’n kultuur van misdaad en geweld. Hierdie verhoudings is gedeeltelik gebaseer op argumente van algemene spanningsteorie, sosialeleerteorie, differensiële-assosiasie-teorie en roetine-aktiwiteitsteorie. Die model is met stawingstoetse geëvalueer en die gevolgtrekking is gemaak dat die model geskik is vir sy beoogde doel. Verskeie scenario’s wat daarop gemik is om Suid-Afrikaanse roof te verlaag deur die verhoging van opleidingsvlakke is daarna deur die model gesimuleer.

Oor die algemeen dui die simulasie-resultate daarop dat dit lank sal neem voor die verbetering van die Suid-Afrikaanse opleidingsvlakke ’n beduidende effek op die afname in roofvoorvalle sal hê. Die resultate dui egter daarop dat sodanige intervensies ook langdurige effekte oplewer en gevolglik sal dit lank neem om die effekte om te keer. Verder dui die resultate aan dat kombinasies van intervensies kragtiger effekte oplewer as die som van effekte wat geproduseer word deur intervensies wat in isolasie toegepas word.

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- My family and friends for their ongoing moral support throughout the development of this study. Several challenges were faced and their encouragement kept me going.

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List of Abbreviations

ABET	Adult Basic Education and Training
AET	Adult Education and Training
CEMIS	Centralized Education Management Information System
CLD	Causal loop diagram
CSVR	Centre for the Study of Violence and Reconciliation
FBI	Federal Bureau of Investigation
FET	Further Education and Training
GDP	Gross Domestic Product
GEAR	Growth, Employment, and Redistribution Strategy
GHS	General Household Survey
HEDA	Higher Education Data Analyzer
HII	Household income inequality
III	Income Inequality Indicator
LTPC	Less than primary completed
NCPS	National Crime Prevention Strategy
NDP	National Development Plan
NIDS	National Income Dynamics Study
NQF	National Qualifications Framework
NSC	National Senior Certificate
PC	Primary completed
QLFS	Quarterly Labour Force Survey
REC	Research Ethics Committee
SA	South Africa(n)
SAPS	South African Police Service
SAQA	South African Qualifications Authority
SD	System dynamics
SMSA	Standard Metropolitan Statistical Area
SSC	Secondary school completed

SSNC	Secondary school not completed
TEC	Tertiary education completed
TVET	Technical and Vocational Education and Training
WPSS	White Paper on Safety and Security

CHAPTER 1

Introduction

Contents

Research is formalised curiosity. It is poking and prying with a purpose. - Zora Neale Hurston

This chapter serves as an introduction to the study by briefly discussing the problem investigated, as well as the approach used for the investigation.

1.1 Background

Crime statistics published by the South African Police Service indicate that the total number of recorded crimes, classified under the 17 community-reported serious crimes, have decreased from 1,885,881 during the 2008/2009 financial year to 1,629,319 during the 2019/2020 financial year, as can be seen in Figure 1.1. On the other hand, robbery at residential- and non-residential premises has increased over the last twelve years in South Africa. Figure 1.2 shows the trend of robberies at residential- and non-residential premises, which are part of the 17 community-reported serious crimes, recorded by the South African Police Service. Robbery at residential premises has risen from 18,438 incidents during the 2008/2009 financial year to 21,130 incidents for 2019/2020. Similarly, robbery at non-residential premises has risen from 13,885 to 20,651 incidents during the same period. This shows that, in general, recorded crime incidents in South Africa are decreasing, but annually recorded incidents of robbery at residential- and non-residential premises have gradually increased over the last twelve years. From this it may be said that governmental strategies to reduce crime in South Africa have been effective, but not for all types of crime.

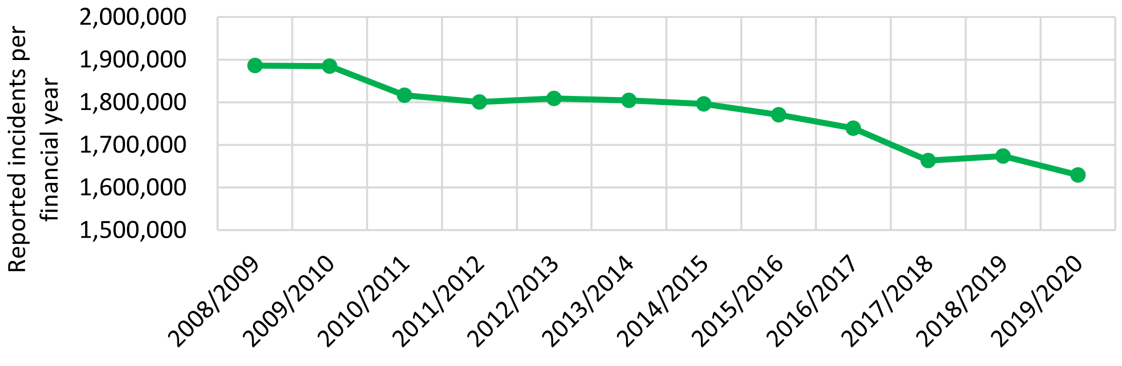

Figure 1.1: Total number of incidents of the 17 community-reported serious crimes recorded in South Africa for the financial years 2008/2009 to 2019/2020 (South African Police Service, 2019: p. 7)

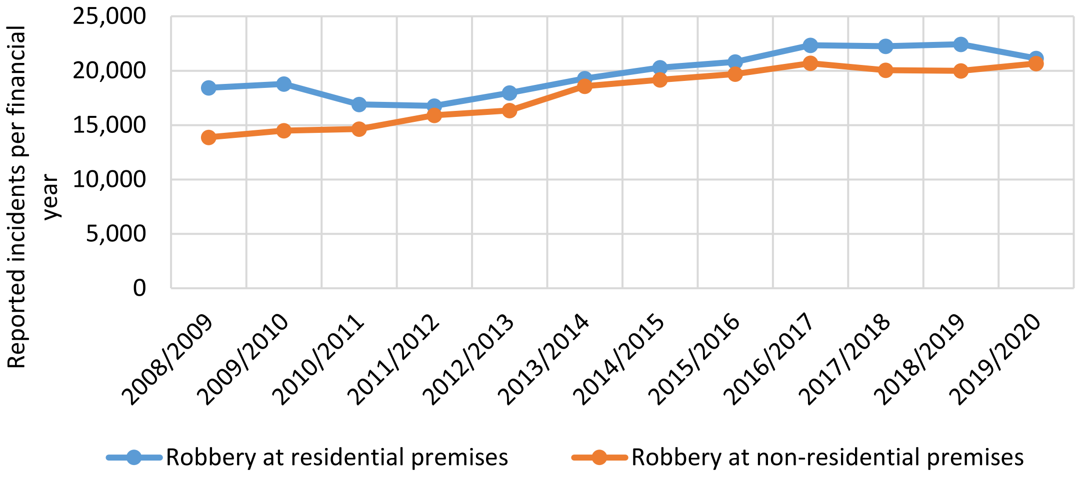

Figure 1.2: Incidents of robbery at residential- and non-residential premises recorded in South Africa for the financial years 2008/2009 to 2018/2020 (South African Police Service, 2019)

It should be noted that South Africa has undergone some changes in its approach to addressing crime. In 1996 the National Crime Prevention Strategy (NCPS) was developed for South Africa. The four focus areas of the NCPS consisted of improving criminal justice functioning, environmental design, community values and education, and transnational crime. In 1999, a change in administration led to a new approach in combating crime in South Africa. This occurred because the growing crime problem placed political pressure on the government. As the longer-term approach of the NCPS had not eased the fears of the public or the politicians, the Growth and Development Strategy was replaced with the Growth, Employment, and Redistribution Strategy (GEAR) and this led to the replacement of the NCPS with the National Crime Combating Strategy (NCCS) in 2000. It is worth noting that the NCPS was largely drafted by a panel of civilians and was widely distributed for comment. The NCCS, on the other hand, was produced in-house by the South African Police Service (SAPS) and has never been issued as a public document. The NCPS was, in theory, an interdepartmental policy, whilst the NCCS is explicitly a security cluster matter (Du Plessis & Louw, 2005: pp. 430-431).

In 2016 the Civilian Secretariat for Police published the White Paper on Safety and Security (WPSS). The white paper has two objectives: 1) to provide an overarching policy for safety, crime and violence prevention accompanied with an appropriate framework, 2) to facilitate the creation of a sustainable, well-resourced implementation and oversight mechanism. *The focus of the white paper is crime and violence prevention and seeks to realise the vision of the National Development Plan (NDP)* (Civilian Secretariat for Police, 2016). It is of interest to this study that the Civilian Secretariat for Police advocates a *knowledge-based approach* in the 2016 White Paper on Safety and Security by stating that

> [i]nterventions and programmes employed must be based on demonstrated and proven results. The availability of data is a critical component of planning and evaluating strategies and interventions. The collection of reliable data to inform evidence-based interventions is an essential component of the crime and violence prevention approach advocated in this White Paper (2016: p. 13).

Public policies often fail to achieve their specified goals. This stems from the environment and the policy-making process. Traditional policy-making approaches have several problems. Two of these are 1) the need and cost of experimenting and 2) the need to persuade different stakeholders. It has been argued that system dynamics models can be useful for policy-making because the characteristics of such models address these problems (Ghaffarzadegan, Lyneis & Richardson, 2015). System dynamics has previously been used to evaluate polices with regards to crime (Quijada *et al.*, 2005; Jaén & Dyner, 2008, 2014; Yu & Fang, 2017; Nyabadza & Coetzee, 2017). However, none of these studies have had a specific focus on robbery.

1.2 Problem statement

Relying on the information provided in the previous section, the following statement is meant to concisely capture the problem addressed by this study:

Interventions for reducing crime in South Africa have been implemented as well as changed in the past and, in general, annually recorded community-reported crime has decreased gradually over the last twelve years. However, recorded incidents of robbery at residential- and non-residential premises in South Africa have risen during the same time span.

The research scope, research aim and research objectives presented in the following three sections are based on the problem statement and depict this study's approach to address the identified problem.

1.3 Research scope

For defining the scope of this study, the South African National Development Plan (NDP) for 2030 was taken into consideration. The NDP 2030 is a plan developed specifically for eliminating poverty and reducing inequality in South Africa by 2030 (National Planning Commission, 2012b: p. 1). This may be achieved by addressing the underlying driving forces of poverty and inequality, by shifting the focus from developing short-term and symptom-based policies to longer-term policies that are based on evidence and sound reason (National Planning Commission, 2012a). Therefore, the scope of this study was aligned with one of the goals of the NDP 2030 by investigating the drivers of aggravated robbery that forms part of violent property crime, in the context of South African education- and income inequality.

1.4 Research aim

As mentioned earlier, the most recent statistics of recorded incidents of robbery at residential- and non-residential premises in South Africa are following an increasing trend despite ongoing crime interventions. As seen in the 2016 White Paper on Safety and Security, the Civilian Secretariat for Police advocates a knowledge-based approach for developing interventions that improve safety and security in South Africa. Therefore, this study attempts to investigate core drivers of robbery, in the context of South African education- and income inequality, with the use of system dynamics in order to identify and test interventions that address these.

1.5 Research objectives

Table 1.1 presents the research objectives that were established in order to reach the research aim.

Table 1.1: Research objectives of the study

Objective	Description
I	*Conduct* a scoping review of literature related to various models of crime, in order to gain insight about previous attempts of studying crime-related problems using mathematical models.
II	*Identify* core drivers of robbery (residential and non-residential) in South Africa, through a conceptual literature review, to enable the creation of a model that may prove useful in developing crime intervention strategies targeting this type of crime.
III	*Formulate* a system dynamics model that captures the fundamental factors relating to the problem at hand.
IV	*Test* the model according to the model testing guidelines discussed by Sterman (2000) to determine the credibility of the model in relation to the problem addressed.
V	*Develop* and *compare* different strategies addressing the identified core drivers in order to reduce the number of annual robbery incidents.
VI	*Recommend* future research for model improvement.

1.6 Thesis organisation

The study was organised to follow the structure provided by Table 1.2, in order to reach the research objectives outlined in Table 1.1.

Table 1.2: An outline for the organisation of the thesis

Chapter	Title and description
Chapter 1	***Introduction*** The research problem is introduced, and the objectives of the study are stated.
Chapter 2	***Methodology*** The methods applied to the study are briefly introduced.
Chapter 3	***Scoping review*** A scoping literature review, concerned with literature of crime models, is described and the results are discussed.
Chapter 4	***Conceptual review*** A conceptual literature review, identifying core drivers of robbery in South Africa, is discussed.
Chapter 5	***Dynamic hypothesis*** A dynamic hypothesis considering drivers of robbery in the context of South African education- and income inequality is presented.
Chapter 6	***Model Results*** The results generated by the simulation model, according to various scenarios, are discussed.
Chapter 7	***Conclusion*** The study is concluded with its main findings and recommendations for further research are given.

1.7 Chapter conclusion

This chapter introduced the problem of rising incidents of recorded robbery in South Africa over the last twelve years even though overall crime rates have been decreasing. It was mentioned that the country has undergone some changes with regards to its approach of addressing crime. The longer-term strategy of the NCPS that was focused on improving criminal justice functioning, environmental design, community values, education and transnational crime, was replaced by the shorter-term strategy of the NCCS. In order to bring about more effective crime prevention strategies, the 2016 WPSS advocated a knowledge-based approach to crime and violence prevention in South Africa. System dynamics has previously been used to for policy development regarding crime and may therefore also prove useful for developing South African robbery prevention strategies.

The problem addressed by the study was explicitly stated along with its research scope and research aim. It shows that the research scope was aligned with the 2030 NDP. Therefore, the research aim was then defined as an attempt to investigate core drivers of robbery within the context of South African education- and income inequality by using system dynamics in order to identify and test interventions that address these drivers. The previously mentioned research objectives are a list of six sequential steps followed in order to achieve the research aim. The following chapters explain the actions taken and results produced to reach these objectives.

CHAPTER 2

Methodology

Contents

Without systematic unity, our knowledge cannot become science
– Immanuel Kant

This chapter describes the methodology that was followed in this study. Firstly, the concept of simulation models, along with the position of system dynamics within them, is discussed. Secondly, the system dynamics methodology is briefly introduced. Thirdly, the system dynamics modelling process, used for this study, is discussed. Then, the scoping review is defined, and its use motivated. Lastly, the model validation procedure is described.

2.1 Simulation models

To date, many attempts have been made to provide a definition of a system. Among these is the definition of Schmidt and Taylor (1970) which states that a system is a collection of entities that act and interact toward the accomplishment of some logical end. Figure 2.1 shows a map that depicts different ways to study a system as defined by Law and Kelton (2000). The first choice one has is whether to experiment with the actual system or with a model of the system. It is often too expensive, dangerous or impractical to experiment with the actual system in question. In such cases, one would rather experiment with a model of a system (Grigoryev, 2015).

When experimenting with a model of a system, the model can either be physical or mathematical. A small-scale model of an airplane in a wind tunnel is an example of using a physical model to study the aerodynamics experienced by the aircraft. Mathematical models are representations of real-world situations that may be used to understand the situation better and therefore allow one to make better decisions (Winston, 2004). The map shows two approaches used to study a system with a mathematical model, namely, an analytical solution and simulation.

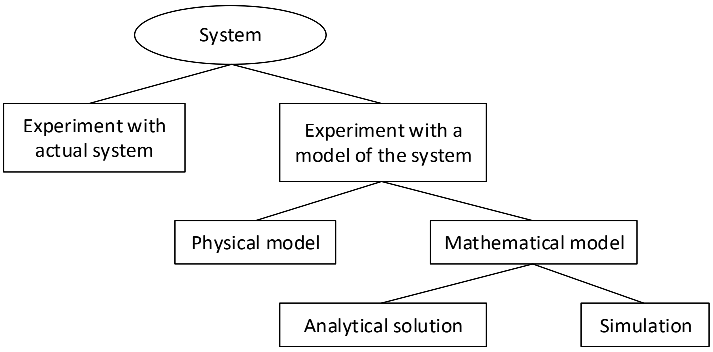

Figure 2.1: Ways to study a system (Law & Kelton, 2000)

Linear programming and queuing theory are examples of analytical models where the goal is to determine optimal solutions. However, real-world problems cannot all be solved in this way. Complexity and stochastic relations of real-world systems usually require that many simplifying assumptions need to be made for analytical models. This can cause the solutions of these models to be inadequate for implementation. In such instances, the decision maker often finds that simulation is the only alternative to modelling and analysis (Winston, 2004).

Winston (2004) defines simulation as a method imitating the operation of real-world systems as they evolve over time. Simulation models generally consist of a group of assumptions about the systems' operation that are expressed as logical or mathematical relationships between the entities of the system. Simulation models have the advantage of requiring fewer simplifying assumptions than analytical models. This allows for much more flexibility in representing the real-world system. After a simulation model is built, it can be used repeatedly to design and analyse different policies to influence the system (Winston, 2004).

Figure 2.2 shows three major approaches in simulation modelling. The approaches are arranged on a scale according to the typical level of abstraction of the modelled systems. System dynamics models can be used to study systems with the highest abstraction level. Such systems include market competition, population dynamics and ecosystems. Discrete event simulation, on the other hand, is used when analysing systems with low to middle abstraction levels. These systems include supply chains, factory floors and pedestrian movement. Agent-based modelling may be used to study systems across all abstraction levels. This is possible, because the agents may represent objects of very diverse nature and scale (Borshchev & Filippov, 2004).

The simulation approaches can be differentiated even further according to the nature of the variables in the system. Discrete event- and agent-based models are mainly used to simulate discrete systems, while system dynamics models are mainly used to simulate continuous systems (Borshchev & Filippov, 2004) and Sterman (2000, p. 872). For discrete systems, the system variables change only at discrete points in time. The service provided by a bank teller is an example of a discrete system. A customer arrives at the teller (or waits their turn in the queue until they are is served), then the customer is served, and then the customer leaves the teller. These events occur at discrete points in time (Winston & Goldberg, 2004). For continuous systems, the system variables change continuously over time. A chemical reaction may be described as a continuous system. Continuous systems are often modelled using differential equations (Winston & Goldberg, 2004).

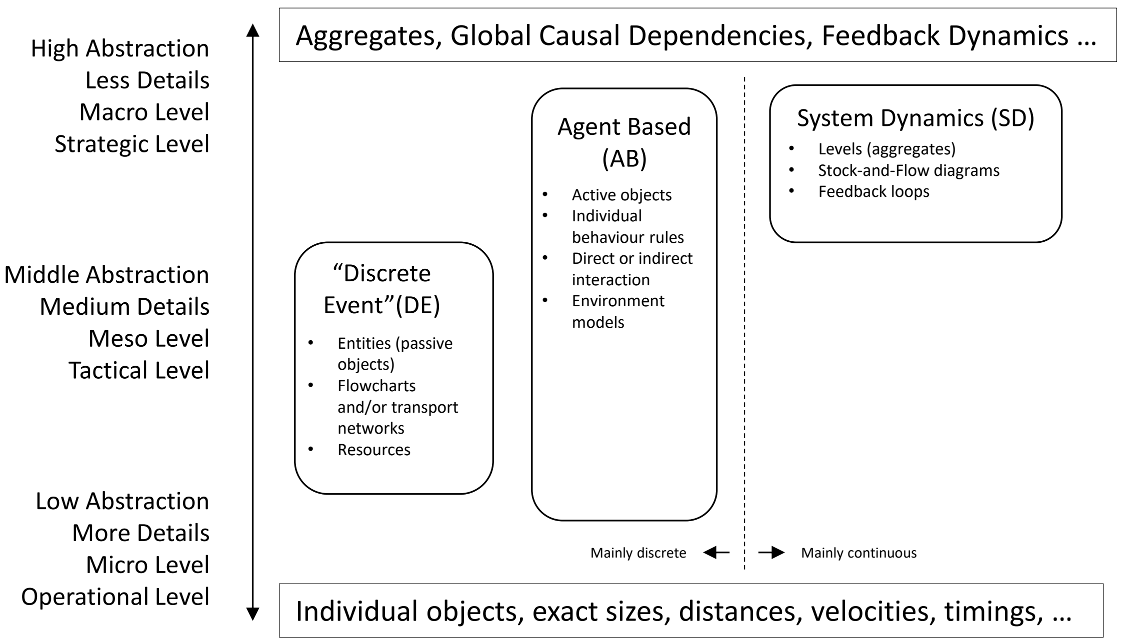

Figure 2.2: Approaches in simulation modelling and abstraction levels (Amended from Borshchev & Filippov, 2004)

2.2 System dynamics

System dynamics methodology was developed in the in the 1950s by Jay W. Forrester to investigate complex interactions, specifically in the supply chain field (Forrester, 1961). Erik Pruyt (2013: p .1) describes system dynamics as 'a method to describe, model, simulate and analyse dynamically complex issues and/or systems in terms of the processes, information, organizational boundaries and strategies' Sterman briefly describes system dynamics as a method to better understand complex systems (2000: p. 4). Since the beginning of system dynamics, the methodology has been used to address public policy issues (Ghaffarzadegan, Lyneis & Richardson, 2011).

System dynamics modelling has several advantages. Some of these advantages are listed below as discussed by Maani and Cavana (2007).

1. *Causal loop diagrams* (and/or stock and flow diagrams) are used to conceptually capture the nature and direction of the relationships in the system being modelled.
2. *Decision rules* can be varied during the simulation because they depend on the state of the system at the time. Static models specify constant relationships that do not consider the feedback effects of the past and the state of the system.
3. *Linear and non-linear relationships* can be modelled.
4. *Physical and information delays* may easily be included.
5. *The approach is not data dependant*. Therefore 'soft' behavioural relationships can be modelled readily.

The initial assumption in system dynamics is that the system is mainly influenced by its own structure (Pruyt, 2013). This structure consists of informational aspects, physical aspects and decision-making processes (Roberts, 1978). Therefore, in order to improve unwanted system behaviours, the system structure needs to be changed. The system dynamics modelling environment allows the researcher to test the consequences of changes to the system structure and thereby find desirable system changes (Pruyt, 2013). Policy development can take place from there. This enables policies to be tested in a scientific manner without affecting the real-world system. That translates into saving capital as well as time in the policy development process.

System dynamics modelling is done using feedback loops, and then by developing stock and flow diagrams. The procedure for creating the basic model of a population is shown below as an example to briefly explain the modelling methodology. Figure 2.3 shows a causal loop diagram (CLD) of a population. CLDs are used during the conceptual modelling phase of the methodology. Causal loop diagrams consist of variables (births, population, deaths) and arrows linking these variables (with polarities). These connections in turn create feedback loops (R1 and B1 in Figure 2.3). The computational modelling of the system is done with software, using stocks and flows as can be seen in Figure 2.4. Additional variables that have an influence on these stocks and flows may then be added, as shown by Figure 2.5.

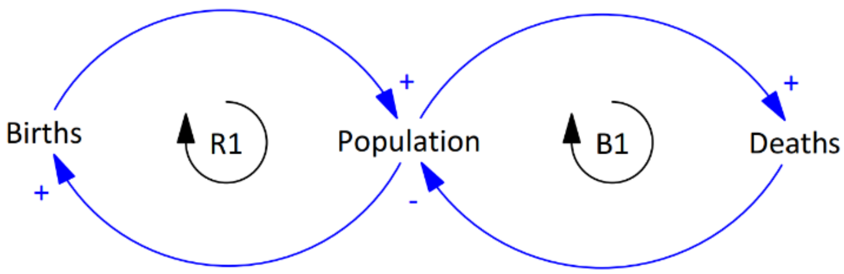

Figure 2.3: Causal loop diagram of a population

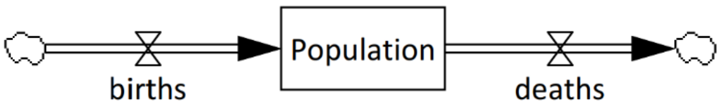

Figure 2.4: Stock and flow diagram of a population

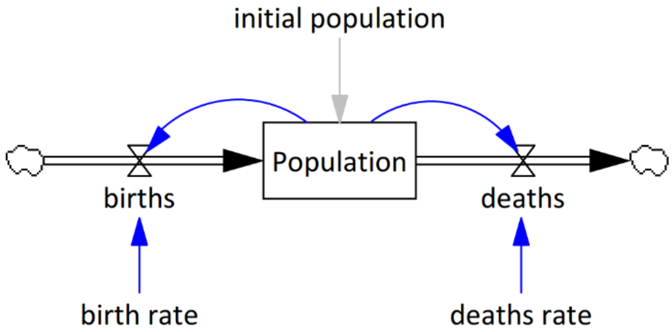

Figure 2.5: Stock and flow diagram with additional variables

2.3 The system dynamics modelling process

Various approaches to the system dynamics modelling process have been proposed in system dynamics literature (Pruyt, 2013). Examples of these are Wolstenholme (1992), Richardson and Pugh (1997), Sterman (2000), Morecroft (2015), Maani and Cavana (2007), Ford (2009) and Pruyt (2013). Table 2.1 shows the comparison of the modelling process steps as described by three of the previously-mentioned authors. The three approaches shown follow the same sequence of processes, but use different naming conventions. All three approaches state that the modelling process is iterative and not a linear sequence of events (Sterman, 2000: p. 87; Maani & Cavana, 2007: p. 62; Pruyt 2013: p. 47).

Table 2.1: Three recently-defined approaches of the system dynamics modelling process

Step	Sterman (2000)	Maani and Cavana (2007)	Pruyt (2013)
1.	Problem articulation	Problem structuring	Problem identification
2.	Dynamic hypothesis	Causal loop modelling	Model conceptualisation
3.	Formulation	Dynamic modelling	Model formulation
4.	Testing	Scenario planning and modelling	Model testing
5.	Policy formulation and evaluation	Implementation and organisational learning	Model use - policy analysis

As can be seen in Table 2.1, authors who have published research after Sterman have defined modelling approaches that follow the same sequence of events he proposed. Sterman accompanies his proposed approach with exceptional support in his book ‘Business Dynamics: Systems Thinking and Modeling for a Complex World’. The book serves as an introduction to system dynamics modelling for the analysis of policy and strategy. It specifically focuses on public policy and business applications (Sterman, 2000: p. vii). Therefore, Sterman’s modelling process was chosen to guide the model development of this study.

As mentioned before, modelling is an iterative feedback process, not a linear sequence of steps. Models are constantly tested and refined during the modelling process. Initially the model boundary and scope are defined. However, throughout the modelling process, the modeller’s basic understanding of the problem might be altered by the feedback received during the process. Iteration may occur from any given step to any other step during the process. Typically, modelling projects will iterate through these steps several times (Sterman, 2000: p. 87). The iterative nature of the process described by Sterman is displayed in Figure 2.6.

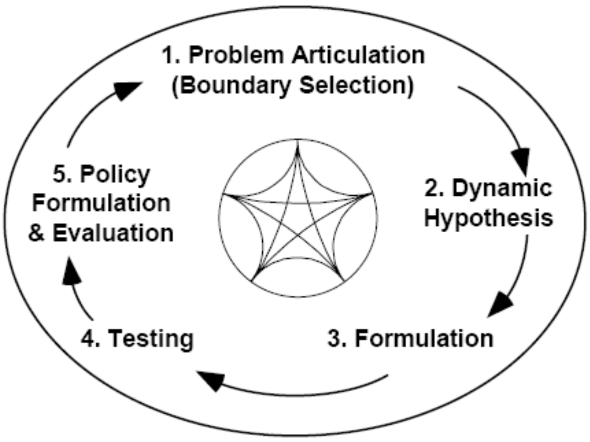

Figure 2.6:The modelling process is iterative (Sterman, 2000: p. 87)

2.4 Scoping review

A scoping review forms part of a range of approaches that may be used to review literature (Grant & Booth, 2009). Scoping reviews have started appearing in literature about 22 years ago (Cacchione, 2016: p. 115). In 2014, a scoping review of 344 scoping reviews revealed that a variety of terms has been used to describe scoping reviews in the literature (Pham, Rajić, Greig, *et al.*, 2014: p. 375). The analysed scoping reviews also varied according to purpose and methodology (Pham *et al.*, 2014: p. 371).

As shown by Cacchione (2016), the methodology used for scoping reviews has evolved over time. In her article, Cacchione (2016) portrays that this evolution may be seen by looking at the methodologies proposed by Arksey and O'Malley (2005), Levac, Colquhoun and O'Brien (2010) and the Joanna Briggs Institute (2015). In order to improve the rigour and consistency of the scoping review process, Levac and colleagues (2010) recommended several additions to the methodology of Arksey and O'Malley (2005). Furthermore, drawing on the previous two methodologies, the Joanna Briggs Institute (2015) proposed several improvements to prescribe their own approach to scoping reviews (Cacchione, 2016: pp. 116-117).

Together with the developments of methodologies, the definition and purpose of scoping reviews also progressed (Cacchione, 2016: pp. 115-116). For this study however, it was only deemed necessary to generate a basic overview of previous mathematical models that have been created to study crime. Therefore, the methodology proposed by Arksey and O'Malley (2005) was recognised as adequate for the study's intended purpose.

To define the scoping review, Arksey and O'Malley (2005) draw on the description provided by Mays, Roberts and Popay (2001). Generally, scoping reviews "aim to map rapidly the key concepts underpinning a research area and the main sources and types of evidence available, and can be undertaken as stand-alone projects in their own right, especially where an area is complex or has not been reviewed comprehensively before" (Mays *et al.*, 2001: p. 194).

Scoping reviews may be conducted for various reasons. Arksey and O'Malley (2005) describe four common reasons for conducting a scoping review. Only one of these is applicable to this study: examining the extent, range and nature of research activity. Although such a review might not describe research findings in any detail, it is a useful way of generating an overview when it is hard to visualize the range of material that might be available (Arksey & O'Malley, 2005: p. 21).

The framework proposed by Arksey and O'Malley (2005) is similar to a systematic review as it also aims to follow a transparent process. This process should be described in a degree of detail that allows others to repeat it (Arksey & O'Malley, 2005: p. 22). For their approach of the scoping review, Arksey and O'Malley (2005) propose a framework of five stages. These stages are listed and briefly described in Table 2.2.

Table 2.2: Proposed stages for conducting a scoping review as defined by Arksey and O'Malley (2005)

Stage	Description
1	***Identifying the research question*** Similar to systematic reviews, one initially needs to identify the research question as this guides the way search strategies are formulated (Arksey & O'Malley, 2005: p. 23).
2	***Identifying relevant studies*** When searching for literature from different sources, practical decisions need to be made regarding the relevance of studies. Considering the study's resources, the coverage of the review, in terms of factors such as language and time span, should be established (Arksey & O'Malley, 2005: p. 23).
3	***Study selection*** To ensure consistency in decision-making, inclusion criteria should be developed based on the specific research question. These criteria determine which studies are selected from the chosen literature sources (Arksey & O'Malley, 2005: pp. 25-26).
4	***Charting the data*** In this stage, key items of information are obtained from the selected studies. In systematic reviews, this process may be called "data extraction". Among others, items to be recorded might include author(s), year of publication and study location (Arksey & O'Malley, 2005: pp. 26-27).
5	**Collating, summarising and reporting the results** Once the key items have been extracted from all selected studies, the review's results may be summarised with tables and figures. These results should be presented in a manner that aids to answer the research question (Arksey & O'Malley, 2005: pp. 27-28).

The framework of Arksey and O'Malley (2005) described above was chosen as a foundation for conducting a scoping review of mathematical crime models. The process followed and the results generated from this review are described in the next chapter.

2.5 Model validation

Sterman does not describe model validation as a method to prove that a model is right, because all models are wrong. Rather, model validation is a process by which one can build confidence that a model is appropriate for the intended purpose (Sterman, 2000: p.845). This section introduces two approaches that were used to validate the model developed for this study. Firstly, interviews that validate the conceptual model and, secondly, various tests for the simulation model.

2.5.1 Interviews for the conceptual model

In their collaborative work Luna-Reyes, Diker and Andersen (2012) describe interviewing as a strategy for the assessment of system dynamics models. They suggest that qualitative validation approaches such as interviews should not be seen as superior to quantitative ones, but rather used as a complementary tool in the validation process.

Luna-Reyes, Diker and Andersen (2012) describe three interview types, namely: structured-, unstructured- and semi-structured interviews. Structured interviews include a formal list of questions in the form of a structured interview script. These questions will be the same or vary only slightly for each interview respondent. Unstructured interviews, on the other hand, allow the direction and questions of the interview to be guided by the interaction between interviewer and respondent. Therefore, the questions and direction of each of these interviews will vary considerably, according the difference in experience and opinion of each respondent. If structured interviews are considered to be on the one end of the interview spectrum and unstructured interviews on the other, then semi-structured interviews lie somewhere in between. In this case, the interview might start with several structured questions and later on proceed in the manner of a conversation (Andersen *et al.*, 2012).

For this study, the semi-structured interview was used as a validation tool for the conceptual model and presented in the form of a causal loop diagram. The semi-structured interview was chosen for this study because it allowed the researcher to ask specific questions regarding the logic of the current conceptual model, whilst allowing the respondent to offer new insights to the researcher at the time of the interview.

2.5.2 Tests for the simulation model

Model testing has unfortunately often been designed to prove that the model is right. As mentioned before, this is not possible because all models are wrong or imperfect representations of reality. Therefore, model testing should rather be designed to uncover the model's flaws in order to understand the model's limitations and possibly improve the model. With this understanding one can then make informed decisions using the model whilst being aware of the model's limitations (Sterman, 2000: p. 845).

Certain system dynamics practitioners make the distinction between model verification tests and model validation tests. For example, Erik Pruyt states that model verification refers to testing whether the model is incorrectly coded or simulated, whilst model validation refers to tests that evaluate whether a model meets the objectives of the simulation study (2013: p. 89). Pruyt refers to testing the adequacy of the selected integration method and step size, checking all equations for errors and testing for dimensional consistency as forming part of model verification (2013: p. 150). According to Pruyt, the tests for boundary adequacy, parameter assessment, extreme conditions and sensitivity analysis form part of model validation (2013: p. 89). However, Pruyt also refers to both verification and validation as forming part of model testing. According to Pruyt, model testing is "a process to uncover errors, improve models, learn, and build confidence in the usefulness of models for particular purposes" (2013: p. 89).

Furthermore, Coyle and Exelby refer to validation as "the process by which we establish sufficient confidence in a model to be prepared to use it for some particular purpose" (2000: p. 28). In their case, this process consists of two aspects. The first is validation, which refers to ensuring that the structure and assumptions meet the model's intended purpose. The second is verification and refers to ensuring that the model's equations are technically correct. Coyle and Exelby refer to validation as subsuming verification (2000: p. 28). The definitions of verification and validation by Pruyt (2013) and Coyle and Exelby (2000) show that these two may be distinguished, but that that they have a common, overarching function: establishing confidence that the model is useful for its intended purpose.

In this study, Sterman's modelling process and related modelling guidelines are used. In Sterman's chapter on validation and model testing, he does not distinguish between verification- and validation tests. Rather, he describes them together as forming part of the model testing process, which has the function of building confidence that the model is appropriate for its intended purpose (Sterman, 2000: p. 845). As mentioned before, model verification- and validation have a common function. Therefore, for this study it was not deemed necessary to distinguish between the two. Both verification- and validation tests, as defined by Pruyt (2013), have been conducted to evaluate the simulation model developed for this study. These particular tests are discussed next.

Forrester (1973), Senge and Forrester (1980) and Barlas (1989, 1990, 1996) developed a wide range of tests to uncover and improve the flaws of system dynamics models. Sterman (2000) summarised the main tests by stating the purpose of each test and the possible tools and procedures for performing the test. The following tables have been amended from the work done by Sterman (2000: pp. 859-861) and these briefly describe the eight tests that have been conducted to evaluate the simulation model developed for this study.

The boundary adequacy test evaluates whether the model boundary has been appropriately defined for its intended purpose. Table 2.3 summarises the purpose, as well as the tools and procedures used for this test.

Table 2.3: Boundary adequacy test (Sterman, 2000: p. 859)

Purpose of the test	Tools and procedures
• Are the principal ideas addressing the problem modelled as endogenous? • Is significant change in model behaviour noted when the boundary assumptions are relaxed? • Does extending the model boundary change previous policy recommendations?	• Model boundary charts, subsystem diagrams, causal diagrams, stock and flow maps and direct inspection of model equations. • Interviews, workshops to seek for expert opinion, archival materials, review of literature and direct inspection or participation in system processes. • Modify the model to include plausible additional structures; make constants and exogenous variables endogenous, then repeat sensitivity and policy analysis.

The structure assessment test, described further in Table 2.4, evaluates whether the model is consistent with the real-world system for which the model is designed.

Table 2.4: Structure assessment test (Sterman, 2000: p. 859)

Purpose of the test	Tools and procedures
• Is the model structure aligned with the available information about the system? • Is the correct level of aggregation used? • Does the model obey basic physical laws (e.g. conservation laws)? • Is the behaviour of actors in the system captured with its decision rules?	• Policy structure diagrams, causal diagrams, stock & flow maps, and direct inspection of model equations. • Interviews, workshops to solicit expert opinion, archival materials, direct inspection, or participation in system processes. • Partial model tests of the intended rationality of decision rules. • Laboratory experiments to elicit mental models and decision rules of system participants. • Develop disaggregate sub models and compare behaviour to aggregate formulations. • Disaggregate suspect structures, then repeat sensitivity and policy analysis.

The dimensional consistency test assesses whether the model equations are dimensionally consistent. The purpose, tools and procedures of the test are shown in Table 2.5.

Table 2.5: Dimensional consistency test (Sterman, 2000: p. 859)

Purpose of the test	Tools and procedures
• Are the equations dimensionally consistent?	• Dimensional analysis software. • Inspect model equations for suspect parameters.

The parameter assessment test, described further in Table 2.6, evaluates whether the parameters of the model have real-world counterparts and if they have been realistically estimated.

Table 2.6: Parameter assessment test (Sterman, 2000: p. 859)

Purpose of the test	Procedures
• Are the parameter values aligned with the available descriptive and numerical knowledge of the system? • Do all parameters have real-world equivalents?	• Estimate parameters using statistical methods. • Calibrate sub systems using partial model tests. • Use judgemental methods based on interviews, expert opinion, focus groups, archival materials and direct experience.

The extreme condition test evaluates whether the model behaves realistically when exposed to extreme conditions. Some of the procedures for this test are shown in Table 2.7.

Table 2.7: Extreme conditions test (Sterman, 2000: p. 860)

Purpose of the test	Procedures
• Do the equations keep making sense when their inputs take on extreme values? • Does the model react feasibly when exposed to extreme policies, shocks and parameters?	• Inspect each equation. • Test response to extreme values of each input, alone and in combination. • Subject model to extreme conditions and test conformance to basic physical laws.

The integration error test examines whether the model is sensitive to the choice of time step or integration method. The model should not be sensitive to either. The procedures used for this test are shown in Table 2.8.

Table 2.8: Integration error test (Sterman, 2000: p. 860)

Purpose of the test	Procedures
• Do the results change when the time step or integration methods are changed?	• Test for changes in behaviour after cutting the time step in half. Test for changes in behaviour after applying different integration methods.

The behaviour reproduction test evaluates whether the model recreates the behaviour of the real-world system being examined. The purpose, tools and procedures of this test are shown in Table 2.9

Table 2.9: Behaviour reproduction test (Sterman, 2000: p. 860)

Purpose of the test	Tools and procedures
• Does the model produce the desired system behaviour? • Is the model endogenously generating the symptoms of difficulty considered by the study? • Do the model's modes of behaviour match those of the real system? • Do the frequencies and phase relationships among the variables match the data?	• Compute statistical measures of correspondence between model and data: descriptive statistics (e.g. R^2), time domain methods and frequency domain methods. • Compare model output and data qualitatively, including modes of behaviour, shape of variables, asymmetries, relative amplitudes and unusual events. • Examine response of model to test inputs, shocks and noise.

Sensitivity analysis examines whether conclusions from the model change, in ways important to its purpose, when assumptions are varied over a plausible range of uncertainty. The purpose, tools and procedure of this test are described in Table 2.10.

Table 2.10: Sensitivity analysis (Sterman, 2000: p. 861)

Purpose of the test	Tools and procedures
• *Numerical sensitivity:* Do the numerical values change notably… • *Behavioural sensitivity:* Do the modes of behaviour simulated by the model change notably… • *Policy sensitivity:* Do the policy suggestions change notably… … when assumptions about parameters, boundary and aggregation are varied over the feasible span of uncertainty?	• Perform univariate and multivariate sensitivity analysis. • Analytic methods such as linearization • Conduct model boundary and aggregation tests as in the first two tests mentioned. • Find the best parameters and policies using optimisation methods. • Find parameter combinations that generate implausible results or reverse policy outcomes using optimisation methods.

The model of this study was tested against the tests mentioned above. The results of these tests are discussed in Chapter 5.

2.6 Chapter conclusion

This chapter described the methodology followed for this study. Firstly, it was explained how system dynamics fits into the picture of modelling methodology. Secondly, system dynamics was briefly introduced. Thirdly, the system dynamics modelling process followed in this study was discussed. Then the scoping review was defined and its use motivated. Lastly, the model validation procedure for this study was introduced. The next chapter will describe the scoping literature review conducted for this study, in order to answer several questions about certain mathematical crime models.

CHAPTER 3

Scoping Review

Contents

If I have seen further, it is by standing on the shoulders of giants. - Sir Isaac Newton

This chapter describes the process followed and the results generated for this study's scoping review. Firstly, the review questions are described in section 3.1. Secondly, the search process followed is described in section 3.2, followed by a description of the results in section 3.3. Lastly, the main conclusions of the review relevant to this study are discussed in section 3.4.

3.1 Review questions

The review was conducted to provide a basic overview of the literature on mathematical models that have been developed for the purpose of studying crime. Table 3.1 presents the review questions that the scoping review attempts to answer. The review does not cover all types of models, but only mathematical models that can be classified as analytical- or simulation models as discussed in Chapter 2.

Table 3.1: Questions that the scoping review of crime models attempts to answer

Review question	Purpose of question
In what *geographic regions* have the reviewed crime models been applied?	The answer to this question will give an indication of how these models relate to the South African context in which this study is applied.
What does *the publishing timeline* of literature dealing with crime models look like?	This will give an indication of the trend of frequency of publication of crime models (e.g. an increase or a decrease). Publications of system dynamics models are of particular interest here.
What *type of crime* has been studied with the reviewed models?	The results for this question will show what types of crimes have been modelled most often and by which type of model.
What are the *theoretical foundations* of these models?	The theoretical foundations of previous crime models may point to theories that could be used for this study.
Have these models been *validated*?	Model validation builds confidence that a model is appropriate for the intended purpose. Therefore, if models are not adequately validated, it is hard to determine their credibility.

3.2 Search process

An initial mapping of the literature was done with various search term combinations. After the initial mapping, four search term strings and two databases were selected. The search terms were applied to the title, abstract and keywords of the literature in the electronic databases Scopus and Science Direct. The search was conducted on 22 May 2018. The first, second, third and fourth search strings were entered as “("system dynamics" AND "crime")”, “("dynamic model" AND "crime")”, “("simulation" AND "crime")” and “(("agent-based model" OR "agent based model") AND "crime")” respectively.

Appendix A contains tables giving the detailed results for each search string used. Figure 3.1 shows an overview of the literature selection process. After an initial search yield of 4708 documents, only 31 documents were selected for the review process. A full list of the selected literature can be found in Appendix A.

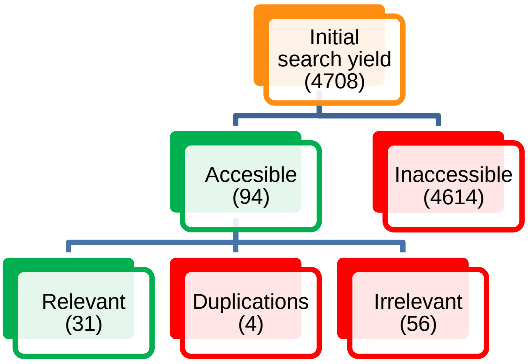

Figure 3.1: Overview of literature selection process

Only one reviewer selected the primary studies for the review. The database search engines were configured to search for the search strings in journal articles, conference papers, theses, dissertations, and government documents. Literature was considered relevant if the study used a mathematical model, as described in Chapter 2, to study a certain type of crime. All literature related to cybercrime was excluded from the review as it was not relevant to this study. No filter was applied to the date of the publications. Information from the literature was manually extracted and recorded in Microsoft Excel. The information extracted from the literature included the title of the study, author name(s), location of application, date of publication, type of modelling approach used, theories referred to and type of validation applied to model.

3.3 Review results

Based on the model classification discussed in section 2.1, the models of the reviewed literature have been classified according to the following three categories; analytical models, system dynamics simulation models and agent-based simulation models. The review identified 15 agent-based models, 11 analytical models and 5 system dynamics models.

Figure 3.2 shows how the reviewed models are distributed among five continents according to their region of application. Only four studies did not apply the models in a specific location. Models from the selected literature have been applied most frequently in the more economically developed continents of Europe and North America. Asia and Africa appear least frequently as the region of application in the reviewed literature. Only two studies were applied to the South African context and these were the only ones applied in an African country. One model focused on drug-related crime in the Western cape Province (Nyabadza & Coetzee, 2017), while the other model focused on rhino horn trafficking (Haas & Ferreira, 2016). This indicates a gap in the literature concerned with robbery models, as well as crime models in general, developed for the South African context.

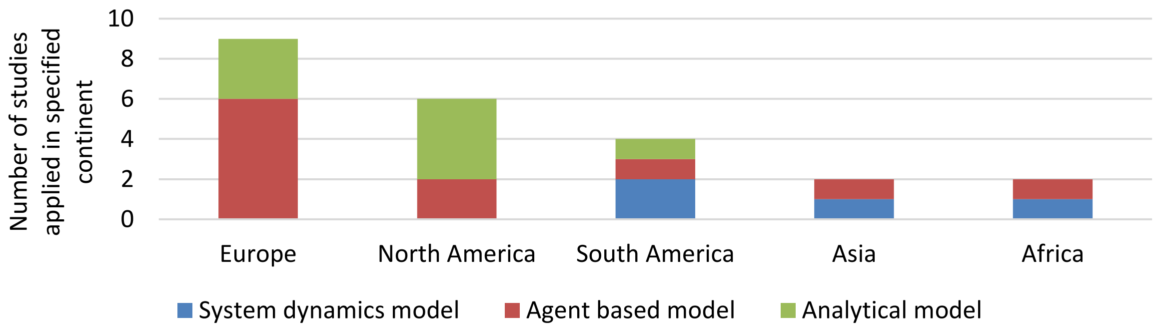

Figure 3.2: Continents of application for system dynamics-, agent-based- and analytical models of crime

Figure 3.3 shows a publication timeline of the reviewed literature according to the three defined model categories. The figure shows that research dealing with *system dynamics models of crime* was, according to the reviewed literature, only published once in 2005, once in 2008, once in 2014 and twice in 2017. Literature concerning *analytical models of crime* appears most consistently on the timeline. The literature with these models appears in every year on the timeline except for 2005, 2009, 2010 and 2017. It should also be noted that the earliest piece of literature on the timeline is concerned with such models and appears in 1984. Publications dealing with *agent-based models of crime* only appear from 2008 onwards. However, in 2016 and 2017 this model category appears more often than the other two categories combined. At the time of the review, the trend of crime model publications seems to be increasing. The increasing trend may be mainly attributed to an increase in the publication of agent-based models. The figure shows that system dynamics models of crime have been published only sporadically since 2005.

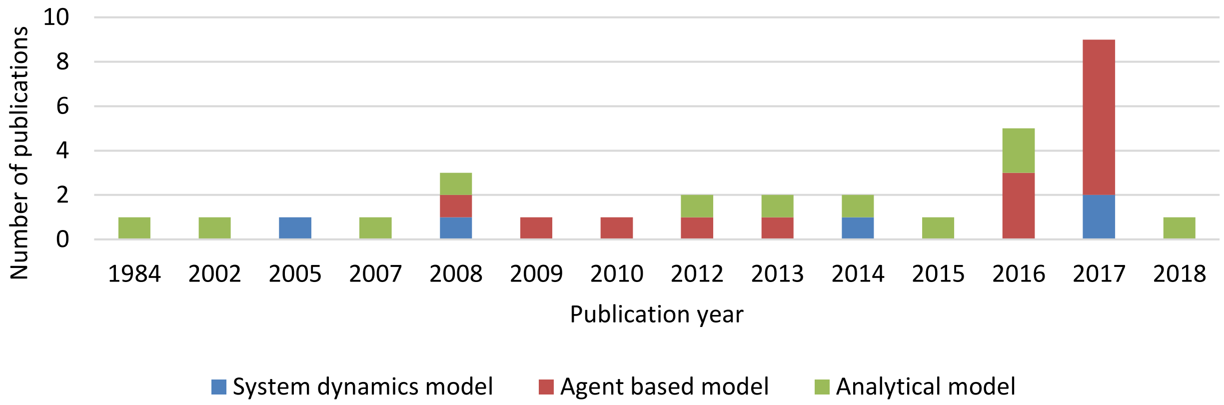

Figure 3.3: Publication timeline of the reviewed literature according to the three defined model categories

The crime types addressed in the reviewed literature have been categorised into 11 different groups, as shown in Figure 3.4. The reviewed literature most frequently addressed crime in a general sense or various crimes lumped together, that is not a specific crime type alone. Four analytical models and three agent-based models were used in the reviewed literature to address this crime category. Models of burglary is the second most frequently occurring crime type in the reviewed literature. This crime category has been addressed through agent-based models only. System dynamics models have been used to address only two of the defined categories; namely crime in urban zones and drug-related crime. The latter crime category has been modelled exclusively using system dynamics. For this study, the most important finding from Figure 3.4 is that robbery had not yet been modelled using system dynamics at the time of conducting the review.

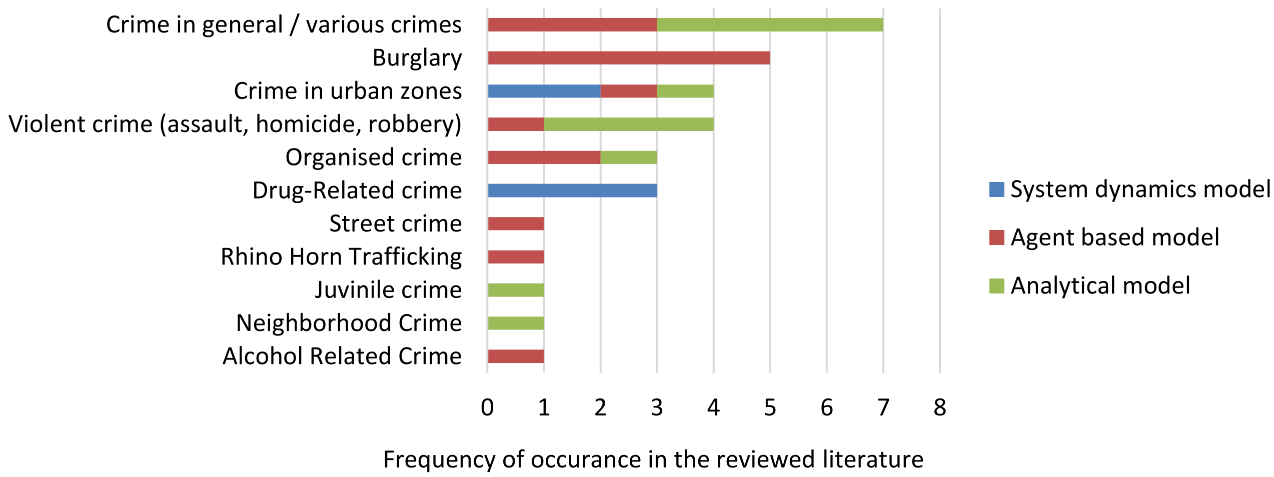

Figure 3.4: Crime types addressed with system dynamics-, agent-based- and analytical models

Out of the 31 models reviewed for the scoping literature review, only ten indicated explicit use of specific theories or categories of theories. Some of these models were based on several theories. Figure 3.5 provides an overview of the different theories used according to each model category. The three theories which occur most frequently are routine activity theory, rational choice theory and crime pattern theory. These theories were found only in the agent-based models in our sample. Out of all the theories and theory categories, only social disorganisation theory was used by different model types. The system dynamics models from the reviewed literature were based on two theory categories: namely organised crime theory and grey system theory. The main concepts of all the identified theories are further discussed in Chapter 4.

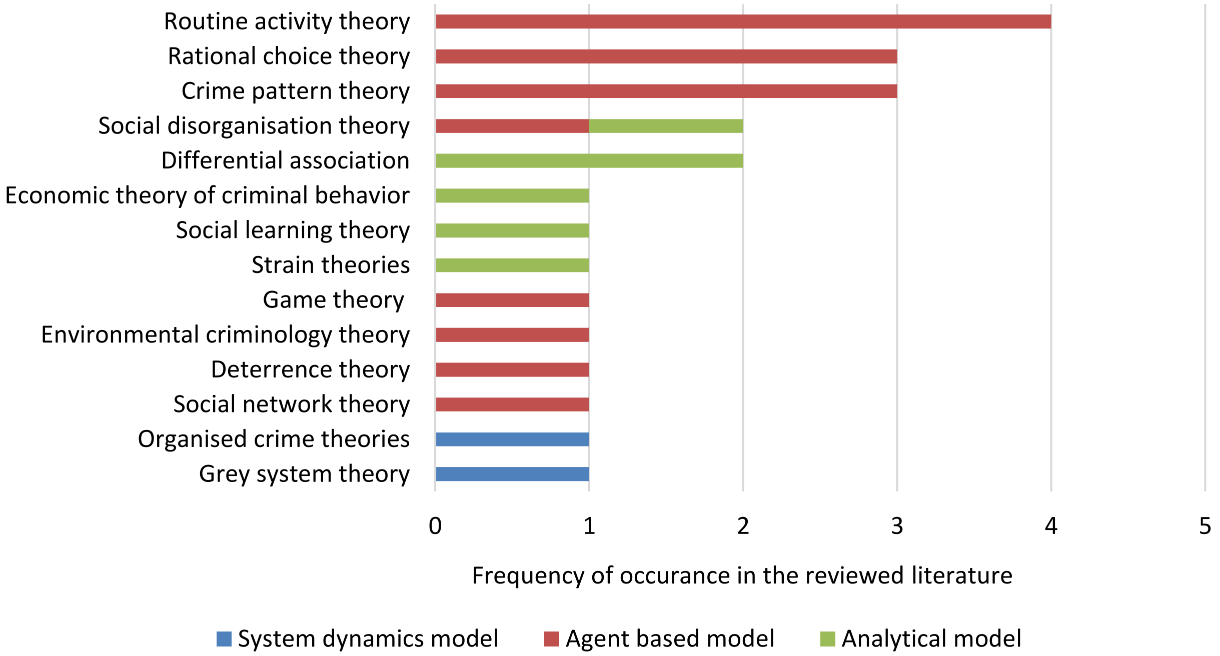

Figure 3.5: Theoretical foundations of some models in the reviewed literature

Sargent (2013) proposed a simplified version of the simulation model development process. In this simplified process, two validation approaches were considered: namely operational validation and conceptual validation. For this review, the testing for operational validity of agent based- and system dynamics simulation models from the reviewed literature was investigated. A simulation model is operationally valid if the model's generated data can be associated with the behavioural data of the real world system (Sargent, 2013). Figure 3.6 shows that the majority of system dynamics- and agent-based models were tested for operational validity. However, when considering more comprehensive validation, only one article discussing a system dynamics model indicated the use of rigorous testing to validate the model. The tests used were those defined by Forrester and Senge (1980) and Barlas (1989).

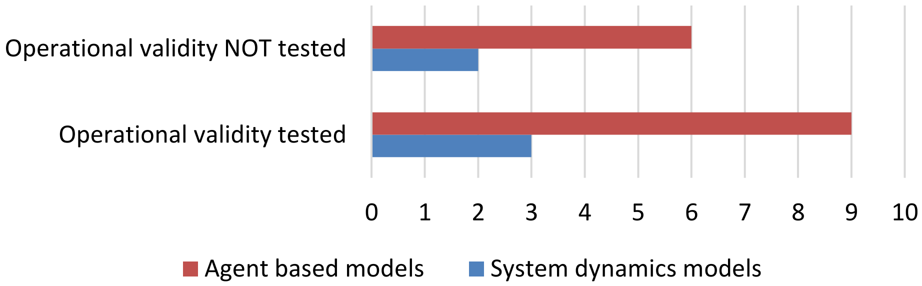

Figure 3.6: Operational validity of simulation models in the reviewed literature

3.4 Chapter conclusions

This scoping review was conducted to generate an overview of existing literature on mathematical crime models. The review revealed that crime models were applied most frequently in Europe and North America, whilst few models were applied in Africa and Asia. Only one system dynamics (SD) model of crime was found for South Africa.

The publication timeline showed that since 2005, literature concerned with SD models of crime has appeared only sporadically when compared to the other two model types. This indicates that minimal research of system dynamics models of crime has occurred in the past.

Analysis of crime types studied in the reviewed literature indicated that SD models of crime were only used to study crime in urban zones and drug-related crime. This implies that SD models which focused specifically on robbery did not appear in the review. The other two model types were used to study a far greater range of crime types. However, one must remember that when compared to literature of the other two model types, far fewer studies of SD crime models had been published at the time of the review.

When the theoretical foundations of the models were considered, it was shown that routine activity theory, rational choice theory and crime pattern theory occurred most frequently in the literature. However, none of these were applied to SD models. Only two theories were used in system dynamics models: organised crime theory and grey system theory.

Finally, testing for operational validity was considered in the review. The results show that more than half of the reviewed system dynamics models were tested for operational validity. However, only one article discussed the use of rigorous testing as defined by Forrester and Senge (1980) and Barlas (1989) to validate a system dynamics model.

Additionally, the results of the review are an indication of a gap in the literature regarding rigorously validated system dynamics models studying robbery within the South African context. Drawing on the results generated by the scoping review, the next chapter discusses the identified criminological theories in more depth. Some of these theories were selected to serve as part of the foundation of the dynamic hypothesis described in Chapter 5.

CHAPTER 4

Drivers of Robbery in South Africa: a Conceptual Literature Review

Contents

Prevention is better than cure. - Desiderius Erasmus

This chapter serves the purpose of getting a better understanding of the drivers of robbery in South Africa, as well as criminological theories that may be linked with these drivers. Section 4.1 presents a literature review discussing drivers of robbery in South Africa. Then in section 4.2, criminological theory is briefly introduced and the theories identified by the scoping review are explored in more detail. Lastly, all of the presented information is summarised in section 4.3 to provide the argument upon which the next chapter is based.

4.1 Drivers of robbery in South Africa

This section firstly provides an overview of South African crime and shows how aggravated robbery fits into the bigger picture of crime in South Africa. Next, the drivers of South African violent crime will be discussed, in context of South African inequality, in sub-section 4.1.2. In sub-section 4.1.3, the roots of inequality in South Africa are examined. Lastly, a summary of this section is provided in sub-section 4.1.4, linking this section with later sections and chapters.

4.1.1 Defining and contextualising robbery

Chapter 1 stated the problem of an increasing trend of recorded incidents of robbery at residential- and non-residential premises in South Africa. It might be helpful to take a look at the way the South African Police Service (SAPS) categorises serious crimes for annual reports, in order to get an idea of where robbery fits into the bigger picture of crime in South Africa. SAPS publishes an annual report concerning 21 serious crimes committed in the previous financial year. It must be noted that various other crimes are reported in South Africa but these are not included in the annual reports. For the scope of this study, the 21 serious crimes are deemed sufficient to provide a brief overview of the crime situation in South Africa for the period between the 2008/2009 and 2019/2020 financial years.

Figure 4.1 displays how these crimes are classified in the reports. The two main categories differ in the manner that the serious crime is reported: either by the community or as a result of police action. *Robbery at residential- and non-residential premises* are two subcategories of *robbery with aggravating circumstances*, listed under *contact crimes.*

In a concept paper addressing the violent nature of crime in South Africa, the Centre for the Study of Violence and Reconciliation (CSVR) classifies the aforementioned 21 serious crime categories into five crime types in table form (CSVR, 2007: p. 42). The five crime types under which the 21 serious crimes fall are: violent crime, damage to property, property crime not involving violence, commercial crime and crime where there is no immediate victim (crime reliant on police action for detection). Here, robbery falls under the "violent crime" type. The other crimes are then by implication non-violent crime.

A legal definition of violent crime, as provided by the CSVR, may be expressed as:

> *applications, or threats, of physical force against a person, which can give rise to criminal or civil liability, whether severe or not and whether with or without a weapon. When more severe such violence may be associated with intimate violations of the person or the potential to cause serious physical pain, injury or death*. (CSVR, 2007: pp. 33-34)

Figure 4.1: 21 Serious crime categories as annually published in SAPS reports

Robbery may be defined as the theft of property by deliberately using violence or threats of violence to gain possession of it (Burchell, 2005: p. 817). This study is specifically concerned with robbery at residential- and non-residential premises in South Africa. These offences are listed under robbery with aggravating circumstances in the annually released statistical reports of SAPS. In section 1 of the Criminal Procedure Act 51 of 1997 (Republic of South Africa, 1997) robbery, attempted or successful, is defined as aggravated if: 1) a fire-arm or other dangerous weapon is wielded, or 2) grievous bodily harm is inflicted, or 3) the infliction of grievous bodily harm is threatened. This may be performed by the offender or an accomplice on the occasion when the offence is committed, whether before or during or after the commission of the offence (Republic of South Africa, 1997). Additionally, it should be noted that robberies and certain instances of burglary are distinct from most other crime categories as they are both violent crimes, as well as property crimes. Therefore, aggravated robbery may be classified as a violent property crime as indicated in Figure 4.2 (CSVR, 2007: pp. 48, 57).

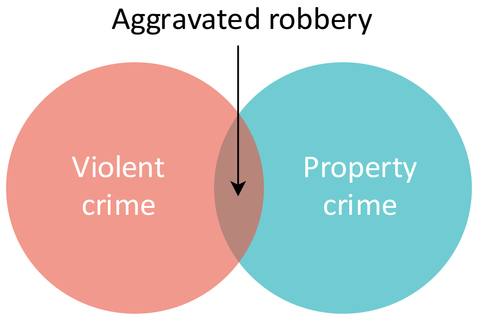

Figure 4.2: Classification of aggravated robbery in South Africa

In South Africa, as well as elsewhere, violence may to some degree be attributed to causes that are different from other crimes. However, in South Africa crime is increasing partly because its environment is generally more conducive for the proliferation of crime (CSVR, 2007: p. 161). It is not possible to give a single explanation for South Africa's high levels of crime and increasing levels of violent crime, but rather a number of explanations exist that may help to understand the driving forces behind them (CSVR, 2007: p. 161; Schönteich & Louw, 2011: p. 1). These explanations should consider, among other causes, the link between the country's violent history, the impact of the increasing availability of firearms, the growth in organised crime and the result of a poorly functioning criminal justice system (Schönteich & Louw, 2011: p. 1).

Additionally, it should be noted that crime may not be prevented only through law enforcement and the criminal justice system. Ideally, criminal acts should be prevented even before the criminal justice system needs to intervene. Therefore, it should be considered that crime and violence may be prevented in various ways through the social crime prevention approaches that address social and economic challenges. Such approaches, however, require commitment and an understanding of the complex dynamics that function in a specific society (Kruger *et al.*, 2016: p. 2). Therefore, explaining the causes of crime and violence in South Africa is not a simple tasks (CSVR, 2007: p. 162).

In a report prepared for the South African Minister of Safety and Security by the CSVR, it is stated that 'the core of the problem of violent crime in South Africa is a culture of violence and criminality, *associated with* a strong emphasis on the use of weapons' (CSVR, 2010: p. 50). The report states that several specific factors may be seen as contributing to sustaining this culture. Some[1] of these factors, as discussed in the report, are listed in Table 4.1 and supported with more recent references.

Table 4.1: Some of the factors described as sustaining the culture of violence and criminality in South Africa (CSVR, 2010: pp. 50-52)

Factor	Description
Inequality	Harris and Vermaak (2015) have investigated the relationship between economic inequality and interpersonal violence in South Africa with homicide rates and several measures of inequality across South Africa's 52 districts. Their results suggest a significant positive relationship between homicide rates and expenditure inequality. Other, more recent studies have produced similar results for countries such as Mexico, Nigeria and Uganda (Enamorado *et al.*, 2016; Adekoya, 2019; Anser *et al.*, 2020). Furthermore, Rufrancos *et al.* (2013) reviewed 17 papers that analysed the relationship between income inequality and several crime types using time-series evidence from various countries. The review revealed that several studies had found significant positive relationships between income inequality and property crime, as well as violent crimes such as homicide and robbery.
Poverty	Using crime data extracted from the South African Police Service database for the period between 1995 and 2016, Cheteni, Mah and Yohane (2018) found a strong association between poverty and drug-related crime in South Africa.

[1] Additional factors discussed in the report include social exclusion, the proliferation of firearms, organised criminal economies and the legacy of war in Southern Africa (CSVR, 2010: pp. 50-52).

Unemployment	In a recent study, Mazorodze (2020) used local municipal-level panel data observed between 2006 and 2017 to investigate whether youth unemployment has a causal effect on murder cases in KwaZulu-Natal. His analysis finds a positive and significant effect of youth unemployment on incidents of murder. In a similar study, Verrinder (2013) observed a positive relationship between youth unemployment and both violent and property crime in South Africa. Additionally, evidence for the relationship between unemployment and both property- and violent crime has been found for Canada (Andresen, 2013).
Beliefs about male sexual entitlement	In a cross-sectional household study with a two-stage randomly selected sample of South African men, Jewkes *et al.* (2011) investigated sexual entitlement as a source for rape perpetration in South Africa. The results show that the most common motivations for rape, acknowledged by the sample of men, stemmed from beliefs of male sexual entitlement.
Alcohol and other substance use and abuse	The study by Carney *et al.* (2013) investigated the relationship between substance use and delinquency among high-school students in Cape Town. The results of the regression model suggest that alcohol- and drug use are significantly associated with criminal behaviour of high-school students in the Cape Town area.
Activity of gangs	Mncube and Madikizela-Madiya (2014) investigated whether gangsterism may be a cause of violence in South African schools. The qualitative study partly consisted of interviews with school stakeholders in six South African provinces. The study's results suggest that gangsterism is one of the external factors that aggravate violence in South African schools.
Other factors	Various other factors may be identified as influencing the degree of violence experienced in South Africa. These may include tolerances relating to violence and crime, inadequate child rearing and weaknesses of the criminal justice system (CSVR, 2010: pp. 50-52). The studies by Manaliyo (2014) Makanga, Schuurman and Randall (2017) demonstrated that community members of townships in the Cape Town area also perceived these as major factors responsible for high crime rates in their communities.

Taking into account the multiple factors mentioned in Table 4.1, it becomes apparent that the problem of high and increasing levels of violent crime in South Africa is complex and multifaceted. In order to achieve focus within this complexity, the scope of this study was aligned with one of the goals of the NDP 2030, as mentioned in Chapter 1, by studying the drivers of aggravated robbery forming part of violent crime within the context of South African inequality. The relationship between inequality and crime, with reference to criminological theory and empirical evidence, will be further discussed in sub-section 4.2.5. Drivers of robbery, in the context of South African inequality, will be discussed in the next sub-section.

4.1.2 Drivers of robbery in the context of South African inequality

The word 'inequality' is rooted in the Latin language and derived from *inaequalitas*, meaning 'not equal', which basically indicates the absence of equality. Inequality[2] may be referred to as an unequal distribution of a specific entity amongst a specific group or population. Thus, to analyse inequality it is necessary to define a specific unit for the entity, in order to determine the entity's distribution amongst a specified group. Inequality may then be defined as the degree of unequal distribution of a specific unit amongst a specified group or population (Charles-Coll, 2011: p. 17).

Various types of inequalities exist and have been named accordingly, such as income inequality (Charles-Coll, 2011), education inequality (Thomas, Wang & Fan, 2001), employment inequality (Doren & Benz, 1998), social inequality (Gilbert & Walker, 2002), gender inequality (Robeyns, 2003) and racial inequality (Oliver & Shapiro, 2006) to name a few. Inequality measures may be

[2] It should be noted that *inequality* differs from *inequity*. *Inequality* refers to a dimensional description for an unequal distribution of an entity among a population. *Inequity* implies that such an inequality is morally wrong (Arcaya, Arcaya & Subramanian, 2015). This study is not concerned with the morality of inequality and therefore it does not consider inequity.

categorised into two main groups, namely the *normative* and the *objective*. *Normative* measures are generally concerned with inequality from a view that accounts for its effects on social welfare. In this case, inequality is not seen objectively and its measurement involves normative factors such as welfare and ethics. On the other hand, *objective* measures of inequality mainly consist of statistical and mathematical tools used to estimate income distribution among a set of individuals (Sen, 1973: p. 24).

In March 2018, the World Bank, in close collaboration with the National Planning Commission Secretariat at the Department of Planning, Monitoring and Evaluation and Statistics South Africa, published a report titled ‘Overcoming Poverty and Inequality in South Africa: An Assessment of Drivers, Constraints and Opportunities’ (Sulla & Zikhali, 2018). Among the countries considered by the report, South Africa is the most unequal country by various measures. South Africa’s expenditure Gini coefficient of 0.63 in 2014 makes it the most unequal country with regards to consumption expenditure. The country is also the most unequal based on wealth distribution. The evidence suggests that these inequalities are passed down from previous generations, implying little change over time (Sulla & Zikhali, 2018: p. 60).

Comparison of income inequality between different countries may be done by using the Gini coefficient. The Gini coefficient was derived by Corrado Gini (1912) as a measure of unequal income distribution and has since been widely used for this purpose. The coefficient ranges from zero to one. A higher Gini coefficient means more income inequality and vice versa. The coefficient approaches one when a single person, within the population N, earns all the income, while the remaining (N-1) inhabitants earn nothing (Kalmijn, 2014).

It should be noted that the Gini coefficient exhibits some limitations as a measure of income inequality. In his long-standing study, Atkinson (1970) discusses some conceptual problems of several inequality measures, including the Gini coefficient. In his study, Atkinson (1970: pp. 255-257) demonstrates that the Gini coefficient is more sensitive to changes of the middle income classes than the upper- and lower income classes. Therefore, the Gini coefficient exhibits a certain bias. Additionally, when the Gini coefficient is estimated from a Lorenz curve[3], different income distributions can generate a very similar, or even the same Gini coefficient (De Maio, 2007: p. 850; Osberg, 2017: p. 574). Therefore, Osberg (2017: p. 574) suggests that aggregate summary indices of inequality, such as the Gini coefficient, should be supplemented with direct examination of the segments of the income distribution which one regards as most important.

Figure 4.3 was created from the World Development Indicators provided by the World Bank. The values are the latest available values for each respective country since 2010. Figure 4.3 shows the three highest ranking countries and the three lowest ranking countries, according to their latest available Gini coefficient. From the available data it is apparent that with 0.63, South Africa has the highest Gini coefficient in the world since 2014. Additionally, it may be noted that South Africa has a history of having a high Gini coefficient, as can be seen in Figure 4.4.

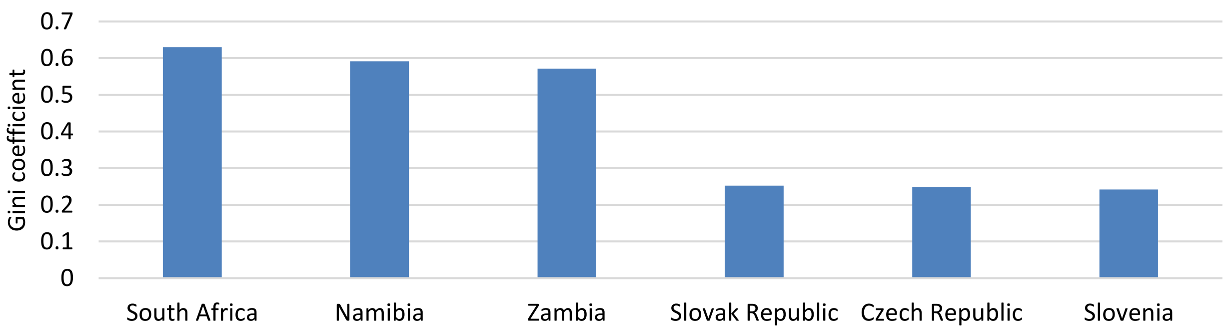

Figure 4.3: Gini coefficient of selected countries (World Bank, n.d a)

[3] The method for estimating the Gini coefficient from a Lorenz is described in the next chapter, under sub-section 5.3.4.

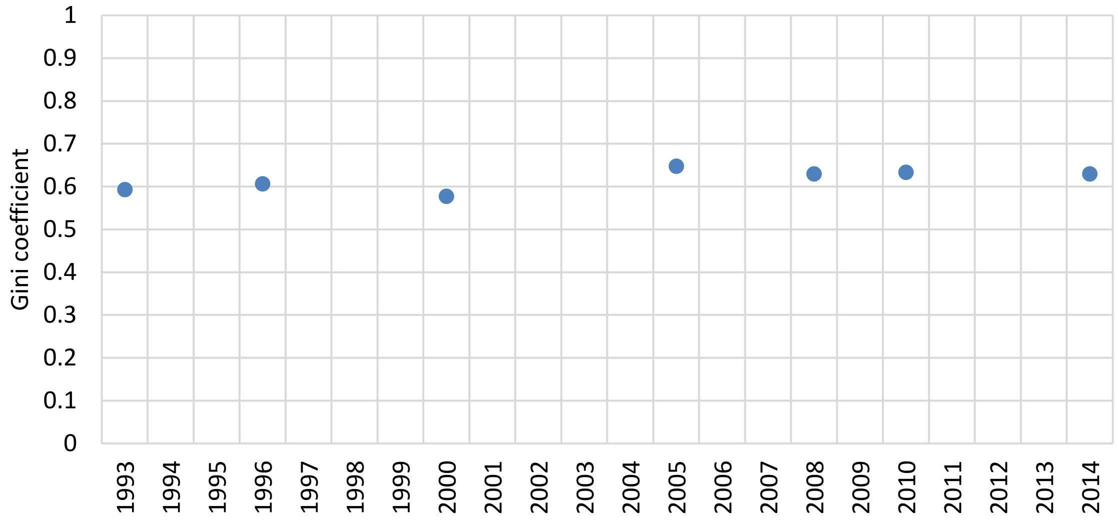

Figure 4.4: South Africa's Gini coefficient history (World Bank, n.d b)

From the Income and Expenditure Surveys for 2005/06 and 2010/11 and the Living Conditions Surveys for 2014/15, Sulla and Zikhali (2018: p. 45) calculated the income shares of the South African population during 2015, as can be seen in Figure 4.5. The figure compares the total annual income of a certain population group with its respective population size. The population groups have been ranked from the lowest earning to the largest earning according to the following percentile ranges: 0-40, 40-75, 75-90 and 90-100. From the figure it can be seen that 41% of the South African annual income has been earned by only ten percent of the population, whilst 40% of the population with the lowest income earned only eleven percent of the total annual income in 2015. This shows the large inequality present in South Africa's income distribution.

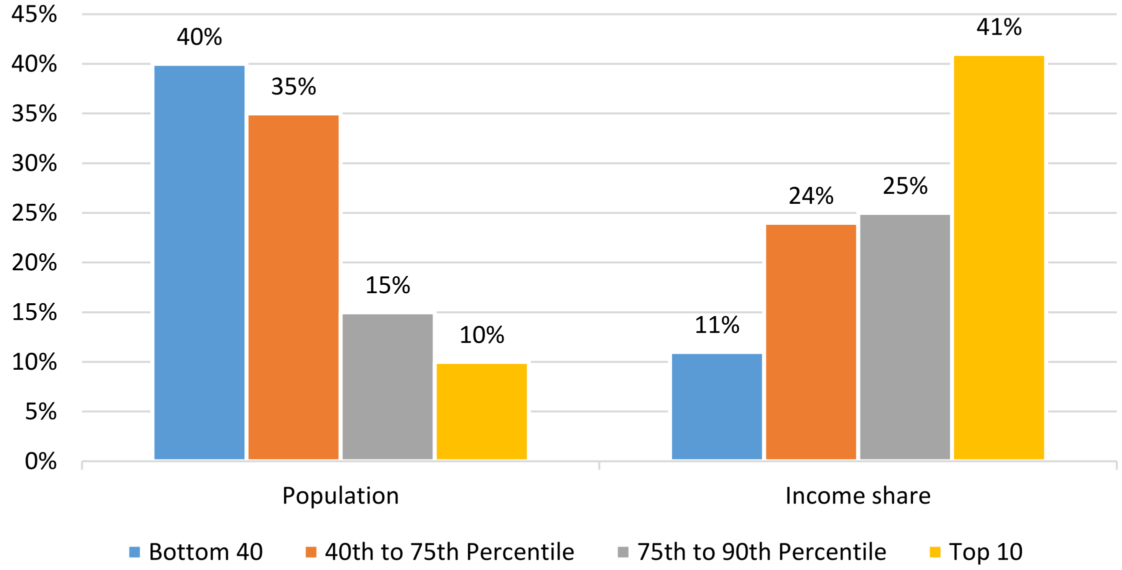

Figure 4.5: Income shares of the South African population in 2015 (Amended from Sulla & Zikhali, 2018: p. 45)

4.1.3 The roots of South African income inequality

Sulla and Zikhali (2018: p. 67) state that among various factors affecting inequality, it seems that education and labour market affiliation are primarily responsible for overall inequality in South Africa. Among other types of inequality, South Africa is marked by high wealth inequality. This arises from high income inequality and inequality of opportunity for children (Sulla & Zikhali, 2018: p. 42).

Additionally, regression results from their study suggest that education and higher-skilled occupations have a positive effect on upward intergenerational mobility. The regression analysis indicates that higher levels of education[4] of a family's son are associated with a higher probability that the son will form part of the top 60% of income earners. The results indicate that completing Grade 10, Grade 12 and tertiary education are associated with 17%, 34% and 40% respective increases in the likelihood of the son being in the top 60%. Furthermore, when compared to low-skilled jobs, the possession of a high-skilled job raises the probability of the son being in the top 60% of income earners by 13% (Sulla & Zikhali, 2018: p. 68).

South African schools have been divided into five quintiles in order to improve the equity governmental fund allocation. These quintiles are based on the unemployment rate and literacy rate of the community in which the school is located. Quintile 1 (Q1) schools represent schools serving the poorest 20% of South Africans, whilst quintile 5 (Q5) schools represent schools that serve the richest 20% of South Africans. The motive behind these rankings is that schools serving poor communities should receive more governmental funding than schools serving wealthier communities (van Dyk & White, 2019: p. 1).

In a study investigating higher education access and success of the 2008 National Senior Certificate (NSC) cohort, van Broekhuizen, van der Berg and Hofmeyr (2018) have estimated six-year undergraduate access rates among the cohort, by school quintile and programme type, as may be seen in Table 4.2. The estimations show that learners from poorer schools were far less likely to access university to pursue undergraduate diplomas and undergraduate degrees within six years of writing the 2008 NSC examinations than learners from Q4 and Q5 schools. The difference in six-year university access rates is especially large between learners of Q1 and Q5 schools for undergraduate degrees. In this case learners from Q1 schools are around eight times less likely to achieve access to undergraduate degrees than learners from Q5 schools. This indicates a strong association between school quintiles and learners' opportunity to access tertiary education in South Africa.

Table 4.2: Estimations of six-year undergraduate access rates among the 2008 NSC cohort, by school quintile and programme type (Amended from van Broekhuizen, van der Berg & Hofmeyr, 2018: p. 93)

QUINTILE	DIPLOMAS	DEGREES
Q1	5.8%	4.4%
Q2	6.9%	5.5%
Q3	9.0%	7.4%
Q4	12.6%	13.7%
Q5	14.8%	34.9%

In a working paper, Asmus Zoch (2017) provides evidence for the link between school wealth quintiles and student wealth quintiles in South Africa. Table 4.3 shows the results of calculations using data from the National Income Dynamics Study (NIDS), the Centralized Education Management Information System (CEMIS) of the Western Cape Province and the 2011 Census of South Africa. The results show that more than half of the learners from the Western- and Eastern Cape Province attend schools in the same wealth quintile as their neighbourhoods. In the Western Cape Province, only about 6% of all learners attend schools that are ranked lower than their respective neighbourhoods. On the other hand, about 40% of learners in the Western Cape Province attend schools that are ranked higher than their respective neighbourhoods. The majority of these learners attend schools that are ranked only one quintile higher than their neighbourhood. The difference in school- and learner neighbourhood wealth quintiles of the Eastern Cape Province is quite similar to that of the Western Cape Province. Additionally, these differences for the Municipality of Cape Town are similar to those of the two given provinces. These results provide an indication

[4] For the regression analysis, education is measured by the highest level of education the son achieves (Sulla & Zikhali, 2018: p. 68).

that learner neighbourhood wealth quintiles are strongly associated with school wealth quintiles in South Africa. When considering this along with the information from Table 4.2, it may be deduced that undergraduate access rates of South African learners are strongly related to their respective neighbourhood wealth quintiles.

Table 4.3: Difference in school- and learner neighbourhood wealth quintiles (Amended from Zoch, 2017: pp. 12,37)

		Western Cape	Eastern Cape	Cape Town
(School wealth quintile - student wealth quintile) =	**-4**		0.61%	0.1%
	-3	0.70%	4.26%	2.0%
	-2	0.70%	1.10%	3.7%
	-1	4.70%	9.03%	15.4%
	0	53.89%	58.50%	48.5%
	+1	22.51%	10.54%	19.5%
	+2	7.60%	6.02%	6.9%
	+3	9.85%	9.04%	3.4%
	+4		0.88%	0.5%

Access to- and completion of higher education levels in turn also has a considerable effect on household income. Insight to this phenomena may be gained from investigating results of the General Household Surveys (GHS) conducted between 2009 and 2018 (Statistics South Africa, 2013a, 2013b, 2013c, 2014, 2018a, 2016, 2017, 2018b, 2019). Figure 4.6 shows household incomes[5] according to the highest education level reached by the individual. The results from Figure 4.6 were derived by calculating the averages for the data available from GHS 2009 up to GHS 2018. The education levels considered are: less than primary school completed (LTPC), primary school completed (PC), secondary school not completed (SSNC), secondary school completed (SSC) and tertiary education completed (TEC)[6]. Figure 4.6 shows that about 53% of the population that has obtained tertiary education are living in households of the highest income group. On the other hand, 68.6%, 69.1% and 64.6% of the population that have obtained LTPC, PC and SSNC, respectively, are living in households of the lowest income group. This shows that the completion of tertiary education is a strong determinant of household income in South Africa.

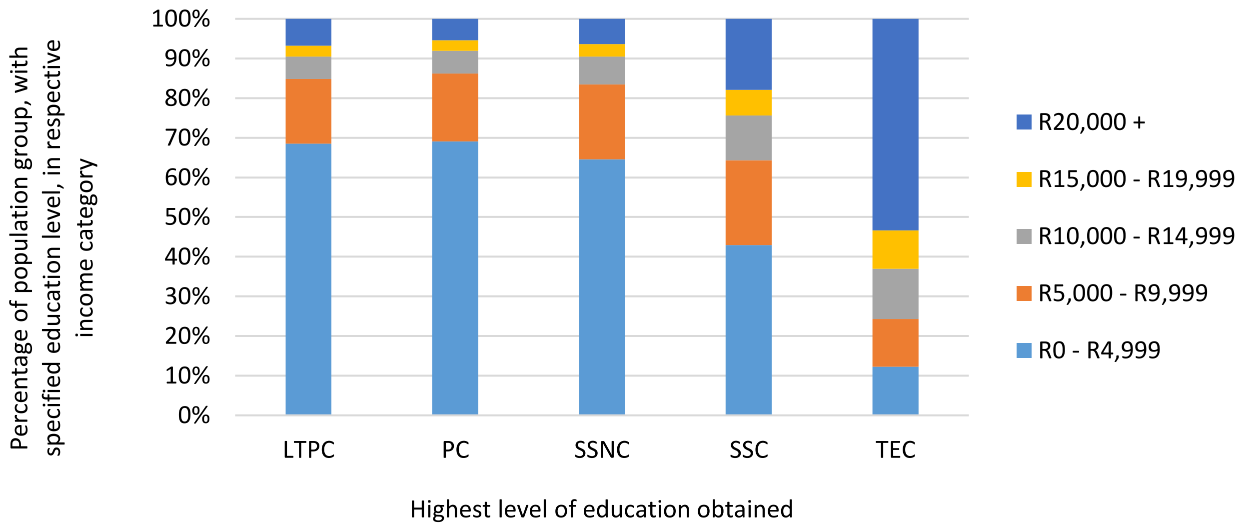

Figure 4.6: Averages of household income according to highest education level of the individual derived from data of the 2009-2018 General Household Surveys

[5] Household incomes were measured in South African Rands per month.
[6] Tertiary education in this case only consists of diplomas with Grade 12/Standard 10, bachelor's degrees, post-graduate diplomas and honours degrees.

4.1.4 Section summary of line of reasoning

As mentioned in this section, explaining the causes of crime and violence in South Africa is not a simple task. Figure 4.7 summarises the arguments found in the literature of this section. Upon investigating crime types recorded by the South African Police Service, it was revealed that aggravated robbery, under which residential- and non-residential robbery falls, may be categorised as being part of violent crime in South Africa. It was argued by the CSVR (2010: p. 50) that a culture of violence and criminality is the core of the problem of violent crime in South Africa. Factors that are seen as contributing to sustaining this culture range from alcohol and other substance abuse to inequality (CSVR, 2010: pp. 50-52).

When ranking countries according to their Gini coefficient, South Africa is at the top of the list. Historical data shows that this income inequality indicator has been high since the introduction of its measurement. A look at South Africa's income shares gives a little more insight into South Africa's income inequality. The largest share of the South African annual income has been earned by only ten percent of the population, whilst 40% of the population with the lowest income earned only 11% of the total annual income in 2015.

Sulla and Zikhali (2018: p. 67) state that among various factors affecting inequality, education and labour market affiliation are primarily responsible for overall inequality in South Africa. Van der Berg (2002) makes the case that South African poverty and inequality are strongly rooted in the labour market, which in turn is influenced by education. It was then discussed that this chain of influence seems to enter a cycle of influence between access to higher education and household income.

The presented study for the 2008 NSC cohort showed that learners from Q1 schools are around eight times less likely to achieve access to undergraduate degrees than learners from Q5 schools. This indicates a strong association between school wealth quintiles and learners' opportunity to access tertiary education in South Africa. Another study indicated that learner neighbourhood wealth quintiles are strongly associated with school wealth quintiles in South Africa. From this it was deduced that undergraduate access rates of South African learners are strongly related to their respective neighbourhood wealth quintiles.

Lastly, the relationship between access to- and completion of higher education levels and household income was investigated. Data from the General Household Surveys conducted between 2009 and 2018 revealed that the greatest proportion of individuals with lower education levels were living in households of the lowest income category while the opposite was true for the individuals having obtained tertiary education. These results show that completion of tertiary education is a strong determinant of household income in South Africa.

This argumentation will be referred to again in later chapters of this study. The next section will give a brief introduction to criminological theory and explain how some of the theories identified by the scoping review, as well as results from empirical studies, may be linked with the arguments of this section.

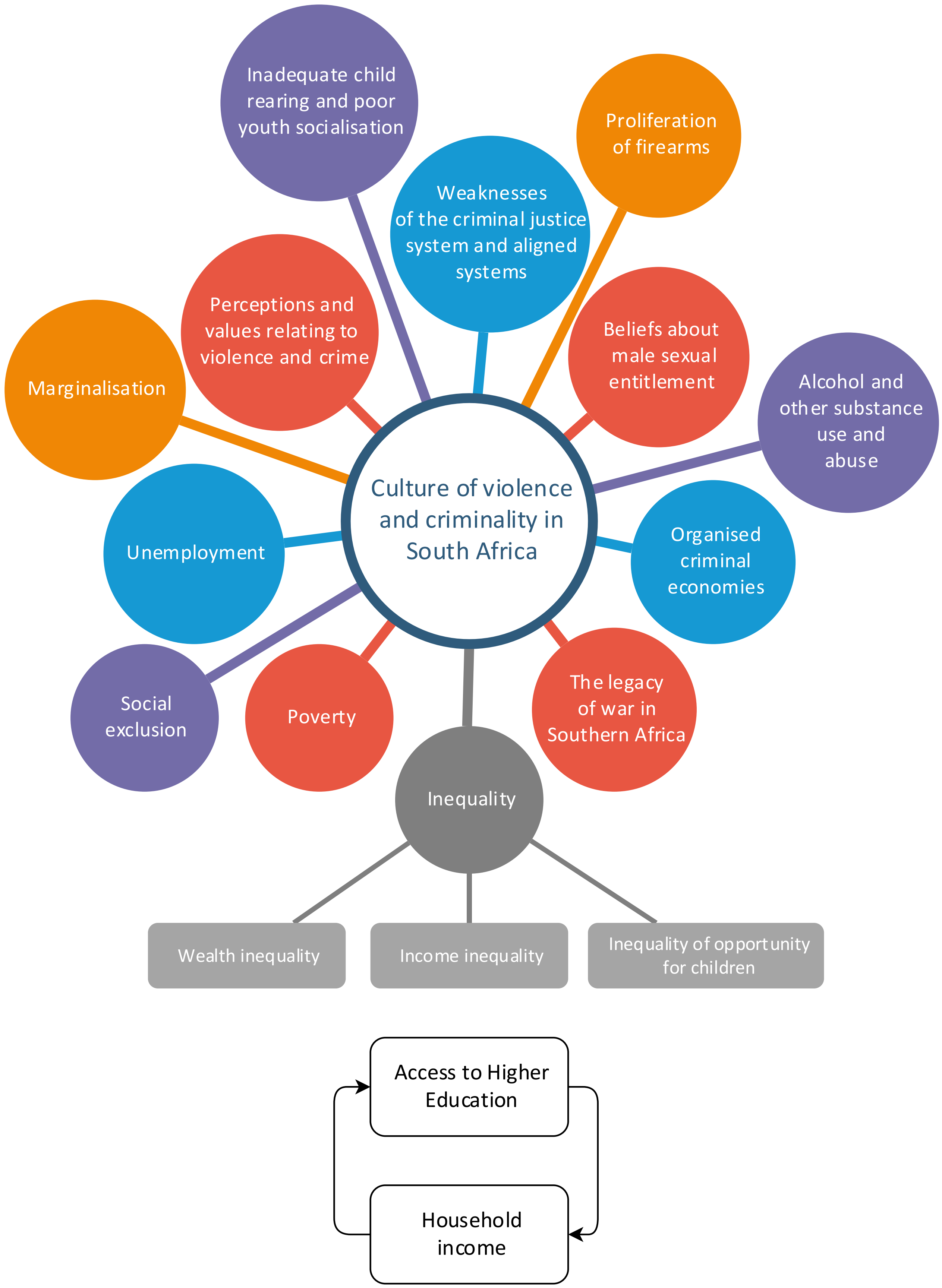

Figure 4.7: Drivers of South African violent crime with a focus on income inequality

4.2 Criminological theory

This section will introduce criminological theory and discuss how it applies to this particular study. Firstly, a brief general overview of criminological theory will be provided. Secondly, the theories identified by the scoping review will be briefly explained and discussed. Lastly, the relationship between inequality and crime, as it is applied in this study, is discussed along with theory and empirical evidence.

4.2.1 A brief overview of criminological theory

According to Akers, '[c]riminological theories are tentative answers to questions about criminal behaviour (or more broadly deviant behaviour) and the criminal justice system (or more broadly the social control system)' (1999, p. 1).

Sutherland (1947) defines criminology as the study of the process of law-making, law-breaking and law-enforcing. Akers (1999) takes this as the starting point for classifying criminological theories. According to Akers, criminological theories can be categorised into major theory types. He elaborates on two of them, as depicted in Figure 4.8. One of these major theory types is concerned with the making and enforcing of the law. Another major theory type attempts to explain law-breaking. Akers also mentions theories that attempt to explain both criminal behaviour and the law. Examples of these are conflict-, labelling-, Marxist- and feminist theories. Akers does mention though that for any classification of theory that is used, 'there will be some kind of overlap, shortcomings, and loose ends' (1999, p. 6).

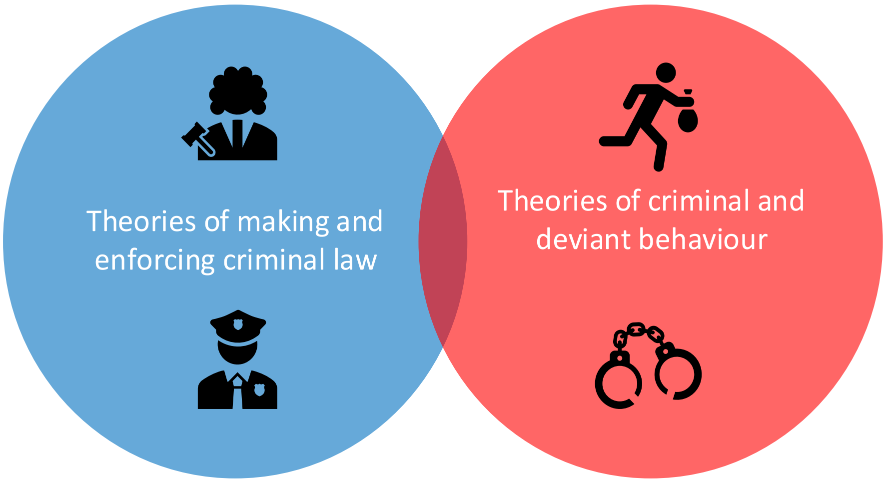

Figure 4.8: Two major categories of criminal theory (Akers, 1999: p. 2)

4.2.2 Theories of making and enforcing criminal law

According to Akers (1999, p. 2), the major group of theories that focus on making and enforcing criminal law attempt to answer the following questions: How or why are specific behaviour and people defined and dealt with as criminal in society? Why is a certain conduct seen as illegal and what determines the action to be taken when it occurs? How are resources of the public and government brought to bear against it? Akers states that the theories attempt to answer these questions by proposing that social, political, and economic factors influence the legislation of law, administrative decisions and rules, as well as the implementation and operation of law in the criminal justice system.

4.2.3 Theories of criminal and deviant behaviour

According to Akers (1999, p. 2), the major group of theories that focus on criminal and deviant behaviour attempt to address the question of *why social and legal norms are violated*. Akers mentions that this question has two interrelated parts. The first part is the attempt to understand the differences in location and the proportion of deviant and criminal behaviour in different groups and societies. The second part is the attempt to explain the differences between individuals who commit from criminal acts and those who refrain from committing criminal acts. In summary, the first part looks at societal and group patterns and the second part takes a closer look at individual differences.

In other words, theories of making and enforcing criminal law focus on the function of the criminal justice system, while theories of criminal and deviant behaviour attempt to explain what drives individuals or groups to violate social and legal norms. As established in Chapter 1, this study attempts to investigate core drivers of robbery within the context of South African education- and income inequality by means of system dynamics. Therefore, theories attempting to explain criminal and deviant behaviour are more relevant to this study than those that focus on the criminal justice system. Both types of theories were identified in the scoping review and will be briefly discussed in the next sub-section.

4.2.4 Theories identified by the scoping review

As seen from the scoping review in Chapter 3, previous models of crime have been based on various criminological and sociological theories. Table 4.4 provides a summary of the theories identified by the scoping review along with their main concepts and the types of models that applied these theories. An attribute of *crime pattern theory* is its assumption that offenders are already motivated. *Routine activity theory* is similar in this way. Agent-based models use these theories because those models are more concerned with short-term crime prediction rather than long-term crime prevention. Therefore, these agent-based models do not consider the underlying causes that motivate individuals to commit the crime. In this study, however, the focus is on the drivers of aggravated robbery; in other words, the underlying causes that motivate individuals to commit this type of crime.

The theories identified by the scoping review are similar in some ways, but have different areas of application and were therefore used by different models for different purposes, as can be seen in Table 4.4. *Differential association theory* and *social learning theory* are both theories that attempt to explain how certain behaviour may be learned from others. These theories are well suited for studying gang-related crime (Winfree Jr. & Freng, 2015). *Rational choice theory*, *game theory* and *the economic theory of criminal behaviour* are concerned with the decisions that individuals make in the context of committing crime (these decisions may be seen as rational calculations of loss and gain). *Social disorganisation theory* and *environmental criminology theory* take into consideration environmental factors that may have an impact on the occurrence of criminal activity. *Deterrence theory* is focused on the implications of punishment on potential and convicted offenders. *Social network theory* and *grey system theory* are not strictly criminological theories. Nevertheless, these concepts have been applied to study crime in a context of social networks and systems. *Organised crime theory* is a category of theories, some of which have already been mentioned, that are used to study organised crime. *Strain theories* are concerned with factors, called strains, that that may act as drivers for committing crime. Strain theories as well as social disorganisation theory will be discussed in more detail in the following sub-section.

Table 4.4: Main concepts of theories used by reviewed crime models

Theory	Main concepts	Types of models applying the theory
Routine activity theory	Routine activities are regarded as general patterns of activities in a society. A key idea is that the structure of routine activities in a society influences the types of situations that emerge. For policy and prevention, this approach has been mainly used for situational crime prevention and policing, such as hot spots analysis (Wikström, 2009).	4 Agent based models
Rational choice theory	This is a general theory of action and is considered as one of the overarching meta-theoretical paradigms in social science. Rational choice theory explains social phenomena as choices of individuals, which may in some way be defined as rational. Choices may be regarded as rational if they meet some criteria as defined by a decision theory and are suitable for reaching specific goals, given the constraints of the specific situation (Wittek, 2017). The rational	3 Agent based models

	choice approach has been applied to various crimes, including robbery, drug use, vandalism and white-collar crime (Wright, 2009).	
Crime pattern theory	This theory defines crime as a complex event that requires many different elements for its occurrence. Crime pattern theory seeks to understand the decision-making process of *motivated offenders* within the context of criminal opportunities and integrates the concept of routine activities. A special emphasis is placed on the geography and spatial patterning of crime to study how the social and physical environment influence criminal events (Brantingham, 2010).	3 Agent based models
Social disorganisation theory	Social disorganisation theory has emerged as one of the most enduring place-based theories of crime. Clifford Shaw and Henry McKay developed this theory and with it shifted criminological scholarship from a focus of the study of people to a study of places. Shaw and McKay proved that delinquency did not occur randomly throughout the city, but was concentrated in disadvantaged neighbourhoods in or alongside areas of industry or commerce (Wickes & Sydes, 2017). For this theory, social disorganisation is defined as low levels of social control mechanisms, such as discipline applied by parents, which are generated by socioeconomic disadvantage, residential turnover and population heterogeneity (Rengifo, 2009).	1 Agent based model & 1 Analytical model
Differential association theory	Differential association is a crime predicting theory. The theory may be described as the process through which individuals have *differential access* to criminal values, given their interaction with other people. Differential association theory makes the claim that criminal behaviour is learned in the same way that law-abiding values are learned. The theory may be reduced to the claim that people become criminals because they have associated with and absorbed pro-criminal definitions (Antwi Bosiakoh, 2012).	2 Analytical models
Economic theory of criminal behaviour	Economic theory of criminal behaviour is an application of the theory of demand. The theory, formalised by Gary Becker in 1968, states that potential offenders are economically rational and respond notably to the deterring incentives of the criminal justice system. According to this, potential offenders compare the gain from committing an offence with the expected cost. If the gain seems to be greater than the expected cost, then the probability for committing the crime will be high (Garoupa, 2014).	1 Analytical model
Social learning theory	The framework for social learning theory was spawned from Edwin Sutherland's Differential Association of the 1940s. He argued that criminal behaviour is learned from intimate peers that have moral definitions that support the violation of the law. The social learning perspective offers a framework that aims to understand the influence of human agency, social forces and peers on criminal behaviour (Holt, 2009).	1 Analytical model
Strain theories	Strain theories propose that certain strains or stressors increase the likelihood of crime. Such strains can lead to negative emotions such as frustration and anger. The negative emotions in turn create urges for corrective action. Crime is one possible response to these urges. An example for this would be an individual experiencing chronic unemployment who may, in desperation, engage in theft or illicit drug selling. In 1992 Robert Agnew developed the general strain theory which has since become the leading version of crime theory. General strain theory takes into consideration a wide range of strains such as the inability to achieve a wide range of goals, the loss of possessions and negative treatment by other individuals (Agnew & Scheuerman, 2011).	1 Analytical model
Game theory	Game theory is the branch of decision theory that considers *interactive decisions* that are applicable whenever the actions of two	1 Agent based model

	or more decision makers together determine an outcome that will affect all of them. The simple concepts of the theory are players (i.e. decision makers), strategies (i.e. alternatives from which the players choose) and payoffs (i.e. numerical representations of the players' preferences among the possible outcomes of the game) (Colman & Krockow, 2017).	
Environmental criminology theory	Environmental criminology evaluates the connection between crime and physical location and how a person's activities are spatially shaped. The theory is specifically applicable to the urban setting. The main goal is to identify ways to change the physical environment in order to reduce opportunities for potential offenders to commit crime at various points in time (Brantingham, 1981). Environmental criminologists may use maps to look for crime patterns using, for example, metric topology (Verma & Lodha, 2002).	1 Agent based model
Deterrence theory	In terms of criminal offending, deterrence is the idea that the threat of punishment will deter potential offenders from committing an offence. Criminal deterrence theory is concerned with two groups of people: caught offenders and potential offenders. For the first group, the punishments imposed on an individual offender may deter that offender from committing further crimes. For the second group, public knowledge of the punishment applied to certain crimes may have a generalised deterrent effect (Wright, 2010).	1 Agent based model
Social network theory	Social network theory depicts social relationships in terms of nodes and connections between those nodes. Nodes are the actors or entities within the networks and the connections are the relationships between the actors. In its basic form, a social network is a map, also called a social network diagram, of all the relevant connections between the nodes being studied. Such a network may then be used to determine the social capital of individual actors (Liu, Beacom & Valente, 2017).	1 Agent based model
Organised crime theories	Organised crimes may be classified according to three broad categories: provision of illicit goods, illicit services and infiltration of business and government (Albanese, 2009). Explanations for organised crime include theories that are concerned with ethnic group unity, attempts by marginalised social groups to improve their social and economic standing, and traditional theories that are used to explain crime in general. Six theories are generally used in an attempt to explain organised crime: rational choice theory, differential association, social disorganization, the queer ladder of mobility theory, alien conspiracy theory and enterprise theory (Tewksbury, 2014).	1 System dynamics model
Grey system theory	Systems which lack information, such as structure, operational mechanisms, and behavioural documentation, are referred to as Grey Systems. Therefore, examples of Grey Systems are the human body, agriculture and the economy (Julong, 1989). Grey system theory was established by Julong Deng in 1982. The methodology focuses on the study of problems involving small samples and poor information. Systems with partially known information may be studied through generating, excavating and extracting useful information from what is available (Liu, Forrest & Yang, 2012).	1 System dynamics model

4.2.5 The relationship between inequality and crime

This sub-section provides evidence for the causal relationship between inequality and crime as discussed in section 4.1. This sub-section begins by discussing various theories advocating this link with a focus on anomie/strain theory that was identified in the scoping review. Literature providing empirical evidence for this relationship is then discussed.

4.2.5.1 Theories advocating the link between inequality and crime

The causal relationship between inequality and crime is advocated by three main ecological theories of crime, namely: Becker's (1968) economic theory of crime, Shaw and McKay's (1942) social disorganisation theory and Merton's (1938) strain theory (Kelly, 2000: p. 530). Rather than substitutes, these three theories should be seen as complimentary where each theory focuses on a different aspect of the link between inequality and crime. Strain theory is focussed on various stresses that may induce crime. Social disorganisation theory examines informal social controls[7] of crime (Kelly, 2000: p. 531). Economic theory of crime primarily examines the rational decision-making process that potential offenders face when weighing up the possible gains of offending against the possible consequences (imposed by the legal system) of being caught (Garoupa, 2014).

In a collaborative effort Akers, Sellers and Jennings (2017) composed an overview of various criminological theories. In their chapter on anomie[8] and strain theories[9], they introduce anomie/strain theory as having much in common with social disorganisation theory. Akers, Sellers and Jennings, (2017: p. 182) describe a social system, such as a community or society, to be *socially organised and integrated* if a common consensus exists on its values and norms, a firm bond is found among its members, and communal interaction occurs in a peaceful manner. The social system is said to be *disorganised* or *anomic* when its social cohesion or integration is distorted, social control is deteriorating, or when its members are in disagreement. Social disorganisation- and anomie theories both advocate *that a disintegration of cohesion within a social system leads to higher rates of crime* (Akers, Sellers & Jennings, 2017: p. 182).

Social disorganisation theory and anomie theory differ according to the proposed mechanism by which disorder increases criminal incidents. *Social disorganisation theory* proposes that rapid change and disorder debilitate a social system's ability to restrain the behaviour of its members. This allows for the growth of criminal values that contrast conventional values and thereby increase the likelihood of crime within the social system. *Anomie/strain theory* proposes that social disintegration specifically debilitates the moral hold that norms and laws have on the members of the social system. In this view crime is likely to occur only if the disintegration is also combined with blocked or limited access to economic objectives. Such an anomic structural condition is said to generate a strain on members of the system. Criminal behaviour then arises as one of the ways that people adapt to this type of strain (Akers, Sellers & Jennings, 2017: pp. 182-183).

Anomie/strain theory strongly relies on the work of one of the founders of sociology, Émile Durkheim. Durkheim (1897/1951) referred to a state of normlessness in modern society as a situation that advances higher rates of behaviour violating social norms. This state he called anomie. Robert Merton (1938) applied Durkheim's approach to modern industrial societies (Akers, Sellers & Jennings, 2017: p. 183). This was the beginning of anomie/strain theory, which was further developed by various other authors such as Agnew (1992), Rosenfeld and Messner (1994) among others (Akers, Sellers & Jennings, 2017: pp. 192-193). Research that looks for empirical evidence for these theories finds some support for their hypotheses, but the relationships are usually not strong (Akers, Sellers & Jennings, 2017: pp. 205-206). On the other hand, research investigating the link between inequality and crime which may be derived from the above description of anomie/strain theories has found greater support. Supporting arguments for the causal link between inequality and crime will be discussed next.

4.2.5.2 Empirical support for the relationship between inequality and crime

In a longstanding study, Danziger used an economic model to investigate the influence of income inequality[10] on robbery using crime rates for 1970, as reported by the Federal Bureau of Investigation

[7] Informal social control refers to the ability of local neighbourhoods to oversee the behaviour of their residents and the proficiency of neighbourhoods to socialise their residents normally (Bursik, 1988).
[8] Anomie refers to a state of normlessness in modern society as a situation that advances higher rates of behaviour violating social norms (Durkheim, 1897/1951).
[9] The words *'anomie'* and *'strain'* are frequently used interchangeably when making reference to Merton's (1938) theory and later theories shaped by his view (Akers, Sellers & Jennings, 2017: p. 206).
[10] Danziger used a Gini coefficient of family incomes as the measure of inequality.

(FBI) for 222 Standard Metropolitan Statistical Areas (SMSAs) in the United States of America. The regression results showed that income inequality had a significantly positive relationship with robbery rates in the 222 SMSAs (Danziger, 1976: p. 293). In a similar study, Jacobs (1981) found correspondingly similar results.

Blau and Blau (1982) tested the hypothesis stating that a specific type of inequality is likely to create conflict, which in turn manifests as incidents of criminal violence. Their results suggest that economic inequality, among other inequalities, does promote criminal violence (Blau & Blau, 1982: p. 126).

Hsieh and Pugh (1993) conducted a meta-analysis of 34 aggregate data studies that reported on violent crime, poverty and income inequality. The meta-analysis showed that the studies generated a total of 76 zero-order correlation coefficients for all measures of violent crime with either income inequality or poverty. 74 of the coefficients were positive and nearly 80% of these were of at least moderate strength (>0.25). The study concluded that both poverty and income inequality are associated with violent crime.

Morgan Kelly (2000) investigated the relationship between inequality and crime using crime data taken from the 1991 FBI Uniform Crime reports. Here, robbery falls under violent crime. The results show that inequality has a strong and robust impact on violent crime for the given data set (Kelly, 2000: p. 530).

Lederman, Loayza and Menéndez (2002) conducted a cross-country study for about 39 countries with national data from the period of 1980-1994. Their study verified that income inequality[11] and growth rate[12] are robust determinants of violent crime incidents for the examined datasets. Fajnzylber, Lederman and Loayza (2002a) conducted a similar study to investigate the robustness and causality of the link between income inequality and violent crime, such as homicide and robbery, across countries. Their results indicate that incidents of the considered violent crime and income inequality are positively correlated, thereby reflecting the causal effect of inequality on crime rates.

Most of the previously-mentioned studies have been conducted with a focus on the United States of America. In their attempt to investigate the influence of local inequality on violent- and property crime in South Africa, Demombynes and Özler (2005) examined, among others, the approaches in some of the aforementioned literature, and identified various limitations. In their study, they addressed these limitations and applied their approach to South Africa. Their results agree with sociological theories which argue that inequality leads to crime in general and also agree with economic theories that associate inequality with property crime. This provides evidence that the causal relationship between inequality and property crime exists for the South African context.

4.3 Chapter conclusions

This chapter presented several findings from literature considering the drivers of violent property crime in South Africa, of which aggravated robbery forms a part. A report prepared by the Centre for the Study of Violence and Reconciliation stated that the core problem of violent crime in South Africa is a culture of violence and criminality that is associated with the use of weapons. Among other factors, inequality was determined as being partly responsible for sustaining this culture. The scope of this study was then defined as learning about the drivers of aggravated robbery in the context of South African inequality with a specific focus on the characteristically high income inequality of South Africa.

A report prepared by the World Bank indicated that education and labour market affiliation were primarily responsible for overall inequality in South Africa. In an article on inequality, van der Berg argued that in order to significantly reduce income inequality in South Africa, a different pattern of wages was necessary. He maintained that this change could only occur if education quality was substantially improved for the largest part of the South African population. It was then discussed that

[11] Income inequality was measured by the Gini coefficient.
[12] Growth rate was measured as per capita Gross Domestic Product (GDP) growth rate.

this chain of influence appears to enter a cycle of influence between access to higher education and household income.

The presented study for the 2008 NSC cohort showed that learners from Q1 schools are around eight times less likely to achieve access to undergraduate degrees than learners from Q5 schools. This indicates a strong association between school wealth quintiles and learners' opportunity to access tertiary education in South Africa. Another study indicated that learner neighbourhood wealth quintiles are strongly associated with school wealth quintiles in South Africa. From this it was deduced that undergraduate access rates of South African learners are strongly related to their respective neighbourhood wealth quintiles. Upon investigating the relationship between access to- and completion of higher education levels and household income in South Africa, it was found that the greatest proportion of individuals with lower education levels were living in households of the lowest income category, whilst the opposite was true for individuals having obtained tertiary education.

Criminological theory was introduced on a high level and the criminological theories identified through the scoping review of Chapter 3 were briefly explained. Further investigation of the identified theories showed that criminological theories may be grouped into categories according to the way they explain various aspects of crime and the criminal justice system. The approach of strain theory seems to align most with the arguments for drivers of South African violent crime as examined in this chapter. Therefore, strain theory was investigated in more detail. Upon further investigation, empirical studies aimed at testing the validity of the theory were found. These studies, however, found only weak relationships for the hypotheses of this theory. On the other hand, research investigating the link between inequality and crime has found stronger support, even in the context of South Africa. These empirical studies provide evidence that the causal relationship between inequality and crime, as argued in this chapter, exists in South Africa.

The next chapter will provide a dynamic hypothesis of the relationship between income inequality and inequality of access to undergraduate tertiary education that serves as a foundational driver of violent property crime, thereby including aggravated robbery, in South Africa.

CHAPTER 5

Dynamic Hypothesis

Contents

Few ideas work on the first try. Iteration is key to innovation. – Sebastian Thrun

This chapter describes a dynamic hypothesis by building on the arguments that were presented in Chapter 4. Firstly, the problem is defined in more detail in section 5.1. Secondly, the dynamic hypothesis is presented in the form of a causal loop diagram (CLD) in section 5.2. Thirdly, the stock and flow model is described in section 5.3. Finally, section 5.4 discusses the model testing results.

5.1 Problem articulation

Problem articulation, which entails defining the purpose of the model and may also be called the boundary selection, is the most important step in modelling. While models are depictions of systems, analysts should refrain from setting out to model an entire social- or business system and instead focus on an observed problem. A system may be defined as a set of interacting components that form a complex unit. For a model to be useful, it must confront a specific problem and provide a simplification of reality to create a depiction of reality that can be comprehended. The resulting model should be basic enough for its assumptions to be assessed. Therefore, the art of building a model is to distinguish between relevant and irrelevant components of the system that relate to the problem at hand. This provides specifications that help decide which components can be ignored so that only necessary components are left (Sterman, 2000: pp. 89-90). This section therefore provides the specifications necessary for deciding what components of the South African 'crime system' are relevant to the problem addressed by this study.

5.1.1 Theme definition

For the problem articulation, Sterman (2000: p. 86) makes the case for defining the theme of the problem. Defining the theme should explain *what* the problem is and *why* it is a problem (Sterman, 2000: p. 86).

For the purpose of making the problem explicit and differentiating between problem, problem symptoms and problem causes, the following analogy is provided. What is referred to as a 'problem' is often actually a symptom of the problem. A headache is an outward manifestation of a biological malfunction or problem in the body. Instead of the cause of the headache, the pain caused by the headache is often regarded as the problem. It is common that pharmaceuticals treat the symptom experienced but not the actual cause of the headache. Similarly, in this study the increasing trend of robbery at residential- and non-residential premises in South Africa is the symptom that is experienced, and this is regarded as the problem. However, to effectively solve problems, it is necessary to understand the causes that generate the problem (Maani & Cavana, 2007: p. 10).

In South Africa, it is not possible to prevent crime solely by means of the criminal justice system. The best situation would be one in which crime is prevented before the criminal justice system needs to intervene. Crime- and violence prevention may be brought about in various ways through environmental approaches and social crime prevention approaches. *Environmental approaches* include situational crime prevention, as well as urban planning activities. *Social crime prevention approaches* are aimed specifically at tackling social and economic challenges in communities to prevent crime. Application of any approach will require commitment as well as an understanding of the complex dynamics that operate within society. One must also acknowledge that differing types of crime and violence occur in different circumstances and have different causes. Therefore, it is extremely important to obtain a thorough understanding of the nature of specific crime problems and their relevant contexts if they are to be addressed effectively (Kruger *et al.*, 2016: p. 2).

As mentioned in the introductory chapter, South Africa continues to experience an increasing trend of robbery at residential- and non-residential premises, *despite* ongoing crime prevention policies. On the other hand, SAPS statistics (2008/2009-2018/2019) reveal that crime in other categories has decreased. This shows that the crime interventions implemented in South Africa are working for some crime types, but not for a**ll**. *The problem therefore is an increasing trend of robbery, despite ongoing intervention strategies, whilst other reported crime is decreasing.* The previous chapter disclosed that the crime type investigated for this study is violent property crime. Therefore, the *causes* for violent crime in South Africa were investigated. The investigation revealed that *a culture of crime and violence* is *the core driver* of South African violent crime. Furthermore, it was discovered that *inequality*, among others, is considered as being one of the factors that are *sustaining this culture*. As the study's scope aligns with the South African 2030 NDP, this study focuses on violent property crime in the context of South African inequality.

5.1.2 Key variables

The second part of problem articulation may refer to explaining which key variables and concepts should be considered for studying the problem (Sterman, 2000: p. 86). This study attempts to investigate, with the use of system dynamics in the context of South African education- and income inequality, to identify and test interventions that address core drivers of robbery. Therefore, the key variables and concepts considered in the study relate to these drivers. Literature and data examined in section 4.1.2 revealed that South Africa has historically suffered from notably high income inequality. Education inequality, specifically unequal access to tertiary education, was identified as a significant cause for South African income inequality. Further on, it was revealed that undergraduate access rates of South African learners are strongly related to their respective neighbourhood wealth quintiles. Therefore, income inequality, education inequality, incidents of robbery and the culture of crime and violence in South Africa were selected as essential components of the problem under investigation. In this study, education inequality specifically refers to unequal access[13] to tertiary education institutions for undergraduate degrees and diplomas that correspond to levels 6, 7 and 8 of the National Qualifications Framework (NQF)[14]. Further details on the variables used to model the problem are discussed in section 5.3.

5.1.3 Time horizon

For the problem articulation, the time horizon of the model should be defined to 1) show the historic behaviour of the roots of the problem and 2) determine how much time in the future should be considered (Sterman, 2000: p. 86). The time horizon should go back far enough into the past to show how the problem emerged and reach far enough into the future to record the postponed effects of possible intervention strategies. A good rule of thumb is to set the time horizon to a little more than

[13] For this study, this inequality is measured as the distribution of tertiary education access among households with differing monthly income ranges.

[14] The National Qualifications Framework (NQF) of South Africa, managed by the South African Qualifications Authority (SAQA), is a framework by which records of learner achievement are registered to enable national recognition of acquired skills and knowledge (SAQA, 2020). The framework categorises qualifications into different levels. A 'diploma advanced certificate' falls under level 6. Advanced diplomas and bachelor's degrees form part of level 7. Postgraduate diplomas and bachelor honours degrees fall under level 8. These mentioned qualifications are primarily provided by universities (Branson *et al.*, 2015: p. 43).

multiple times the longest delay in the system (Sterman, 2000: pp. 90,94). The earliest publicly-available statistics for robbery at residential- and non-residential premises only date back to the 2002/2003 financial year as may be seen in Figure 5.1. This does not determine how and when the problem arose, but it does show that reported incidents of this type of crime have increased since they were first recorded in South Africa.

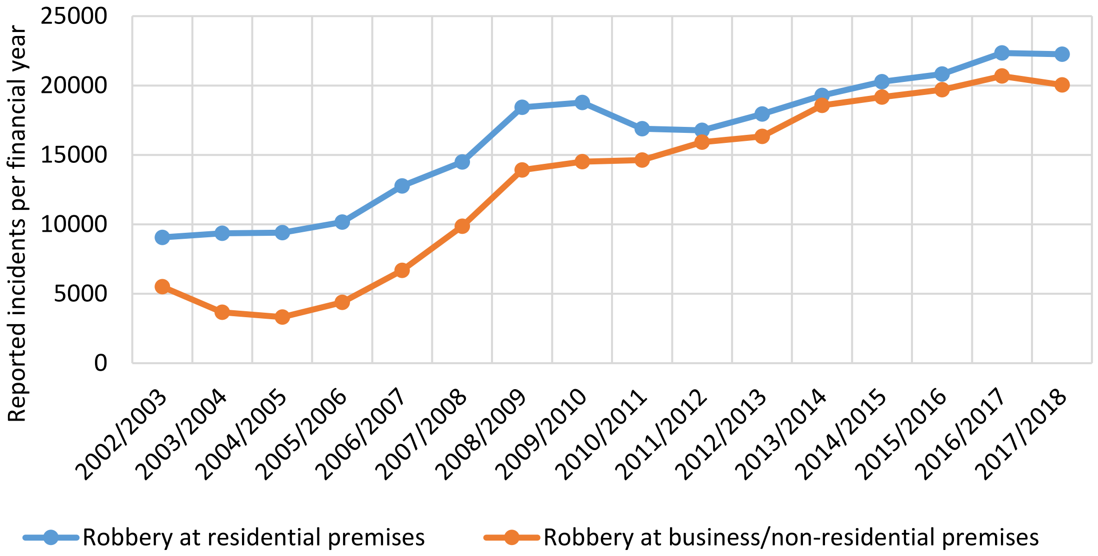

Figure 5.1: Incidents of robbery at residential- and non-residential premises recorded in South Africa for the financial years 2002/2003 to 2017/2018 (South African Police Service, 2009: p. 7, 2010: p. 6, 2019: p. 164)

The model simulates a 122-year period, with a time horizon of 2008-2130. Basic education statistics for South Africa that are available for public viewing and used as reference modes for the simulation model only date back to 2008. Data from the General Household Surveys (GHS) was only available up until 2018. Therefore, the 2008-2018 period was used for model calibration, while the 2021-2050 period was used for projection. The 110-year projection period was used, to allow ample time for long-term effects to become visible as the study is concerned with education- and income inequality which seem to be factors that should be approached with long-term vision. The longest delay in the model is five years. The given time horizon allows projections to be made far enough to estimate how different policies or interventions will perform while moving toward the goals set by the 2030 NDP and beyond.

5.1.4 Dynamic problem definition

The dynamic problem definition, which may also be called the problem reference mode, should define what the historic behaviour of the key problem concepts and variables is (Sterman, 2000: p. 86).

Figure 5.2 shows the trends of education levels of the South African population not attending an educational institution; these were estimated[15] using available data from the General Household Survey (GHS) and the Quarterly Labour Force Survey (QLFS). A brief explanation of the derivation of these trends may be found in Appendix B1. The trends for partially- and fully completed primary, secondary- and tertiary education levels are labelled with abbreviations for the sake of brevity and correspond to the abbreviations previously used for Figure 4.6. All trends are an estimation of the

[15] Estimations were based on the raw numbers obtained through the Quarterly Labour Force Surveys (QLFS) of the first quarters between 2008 and 2018 (Statistics South Africa, 2008b, 2009, 2018d, 2010, 2011, 2012, 2013f, 2014b, 2015, 2016b, 2017b). Two responses from the surveys were merged using the online tool 'SuperWEB2' for accessing datasets from Statistics South Africa (SuperWEB2, no date). The first response specifies an individual's age. The second response specifies an individual's education status, which corresponds to the individual's highest level of education. The second response was grouped into seven categories.

highest education level reached by South Africans who are not attending an educational institution for various reasons. This is estimated as being the final education level in the lifetime of the person in the particular education level category[16].

The trend for South Africans who obtained Grade 1 to 6 as their highest education level, which may be categorised as *less than primary school completed (LTPC)*, is declining. Similarly, the trend for people who have completed primary school (*PC*) as their highest level of education is also decreasing. On the other hand, the trend for South Africans having completed Grades 8 to 11 (*SSNC*) as their highest level of education is increasing. According to the estimations, around 43.3% of the South African population who were not attending an educational institution in 2017 had obtained Grade 8 to 11 as their highest level of education.

This may be the result of a stipulation instituted by the South African Schools Act (No. 84 of 1996). The stipulation governs that

> every *parent* must cause every *learner* for whom he or she is responsible to attend a *school* from the first *school* day of the year in which such *learner* reaches the age of seven years until the last *school* day of the year in which such *learner* reaches the age of fifteen years or the ninth *grade*, whichever occurs first (Republic of South Africa, 1996: pp. 4-6).

Similarly, the trends of South Africans who have completed Grade 12 (*SSC*) or tertiary education (*TEC*)[17] as their highest level of education are increasing. This indicates that more South Africans are completing secondary education and moving on towards tertiary education than in the past. This seems like a positive development, but even though more South Africans are reaching and completing secondary- and tertiary education than in the past, one must keep in mind that that the trend of South Africans discontinuing their studies during the secondary phase is considerable and also increasing.

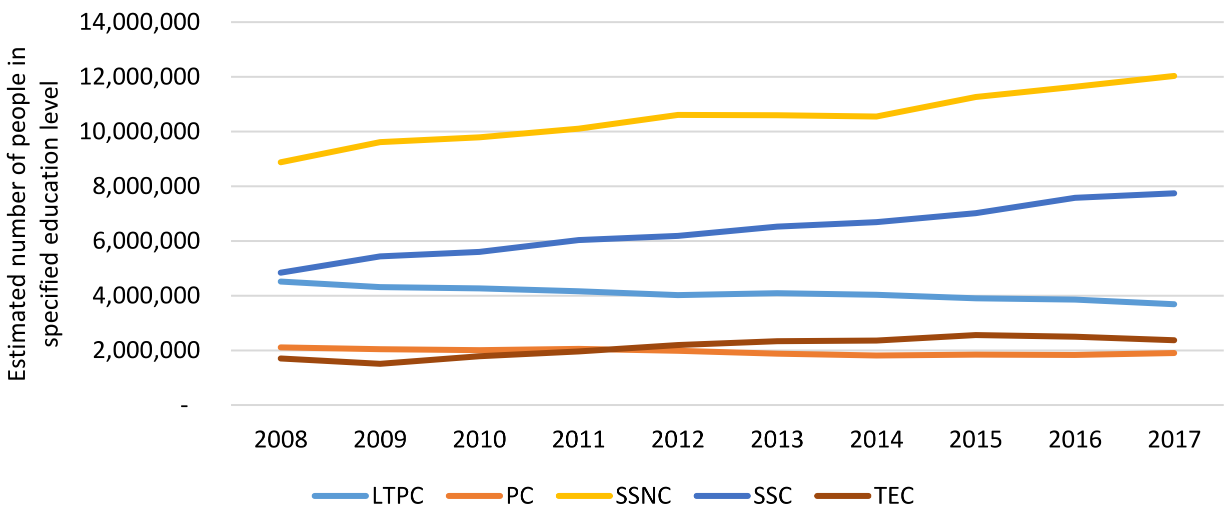

Figure 5.2: Estimated reference modes for education levels of the South African population not attending an educational institution between 2008 and 2017

Figure 5.3 shows estimated household income trends for South Africans of all ages between 2009 and 2017. A brief explanation of the derivation of these trends may be found in Appendix B2. The trends shown in Figure 5.3 only account for South Africans with education levels corresponding to

[16] This, of course, is not completely accurate, because of various reasons. One of the reasons may be that people decide to-, or only receive the opportunity to continue their studies at later stages of their lives. Additionally, the information is obtained from survey data that derives estimates from a certain sample of the population and can therefore not be completely accurate.

[17] Tertiary education in this case only refers to undergraduate degrees or diplomas that qualify as level 6, 7 or 8 of the South African National Qualifications Framework (NQF).

the ones shown in Figure 5.2. From Figure 5.3 it is apparent that the population living in households with an average monthly income of less than R5,000 per month creates the highest lying trend.

From the estimated data it may be gleaned that around 66% of the population with the given education levels were living in households receiving an income of less than R5,000 per month in 2017. From the figure it is evident that a higher household income is associated with a smaller proportion of the population, with exception of the trend of people living in households with an estimated income of R20,000 and more per month. This general pattern should be evident if further categorisation into higher income levels, such as R20,000 – R24,999 and so on, would occur. This is currently not possible as survey data collected from the 2009-2012 GHS specified household income only up to R20,000 per month. Therefore, the subsequent survey data was aligned with this income categorisation to create the trends of Figure 5.3. The relationship between Figure 5.2 and Figure 5.3 can be seen in Figure 4.6 of Chapter 4.

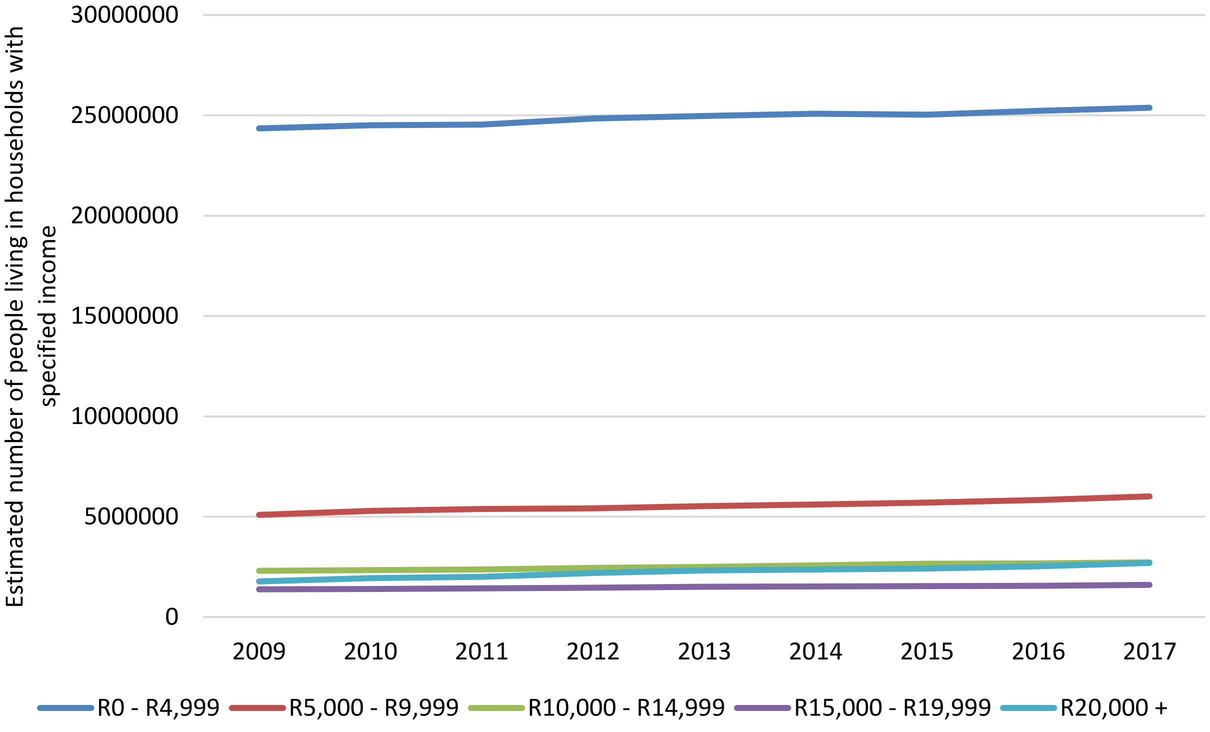

Figure 5.3: Estimated trends for household income categories of South Africans of all ages between 2009 and 2017

5.2 Dynamic hypothesis

In system dynamics, the *dynamic hypothesis* is a theory that accounts for the problematic behaviour studied. The hypothesis is *dynamic*, because it should provide an explanation of the problem's characteristics in terms of the underlying stock and flow structure of the system. This theory is a *hypothesis* because it is always subject to revision as one learns more about the problem from the modelling process and the real world. *In other words, the dynamic hypothesis may be called a working theory that explains how the problem arose.* A large part of the remaining modelling process, from this point onwards, helps to test and improve the dynamic hypothesis (Sterman, 2000: pp. 94-95).

Crime is a problem that is multi-dimensional and complex (Breetzke & Horn, 2008: p. 123). As the entire South African 'crime system' is multi-dimensional and complex, only a small part of the entire system can be investigated with a model. In this manner, the model's purpose acts as a 'logical knife' (Sterman, 2000: p. 89). The dynamic hypothesis of this study is therefore a working theory that attempts to explain the increasing trend of robbery in South Africa in the context of South African education- and income inequality, as previously shown in Figure 5.1.

Figure 5.4 is a simplified representation of the dynamic hypothesis for this study, presented in the form of a high-level causal loop diagram, and indicates some of the underlying forces that have been found to drive robbery in South Africa in the context of income- and education inequality. The hypothesis has been mainly developed from the discussion on drivers of robbery in South Africa and criminological theory, as given in Chapter 4.

The first reinforcing loop (R1) represents the relationship between unequal access to tertiary education[18] and household income inequality as described earlier in section 4.1.3. Here, an increase in household income inequality leads to higher inequality of access to tertiary education. A higher inequality of access to tertiary education in turn also increases household income inequality. An increase in household income inequality also causes an increase in strain, according to strain theory. Then, also according to strain theory, an increase of this strain leads to an increased chance of the occurrence of robbery (Agnew & Scheuerman, 2011). From this point, the second reinforcing loop (R2) emerges.

R2 is mainly motivated by the arguments of social learning theory and differential association theory. For these theories, exposure to certain norms and values means that these norms and values are learned by individuals who are exposed to them (Holt, 2009; Antwi Bosiakoh, 2012). Therefore, an increase in incidents of robbery causes a higher exposure to norms and values that view robbery as a legitimate means of reducing the strain that is caused by household income inequality. It follows that more of these norms are learned by individuals in the society. An increase of these norms then leads to an increase of the culture of crime and violence in the society and therefore acts as a sustaining factor. This, in turn, leads to more incidents of robbery. The first balancing loop (B1) also emerges from this point.

B1 represents short-term efforts of the government to reduce the number of robberies. These focus on a quick reduction of the chances of possible robbery incidents that would be committed by already motivated potential offenders. Here, the force that motivates people is not addressed, but rather the factors that are needed for crime to occur. According to routine activity theory, a criminal act minimally requires three elements. These elements are *1) a potential offender*, *2) a suitable target* and *3) the absence of guardians* that might prevent the act from occurring successfully (Cohen & Felson, 1979: p. 590). In B1, the government aims to eliminate elements two and three to reduce incidents of crime. The final balancing loop (B2) also emerges from incidents of robbery.

B2 represents long-term efforts of the government to reduce the core drivers that motivate people to commit robbery. According to routine activity theory, as defined by Cohen and Felson (1979: p. 590), this strategy addresses the first element required for a criminal act to occur: a potential offender. Addressing the factors that motivate people to commit robbery may be done in various ways. In this study however, the focus is on South African income- and education inequality. Therefore, the motivation to commit robbery will be addressed by targeting South African income- and education inequality.

[18] As in Chapter 4, tertiary education in this case only consists of diplomas with Grade 12/ Standard 10, bachelor's degrees, post-graduate diplomas and honours degrees.

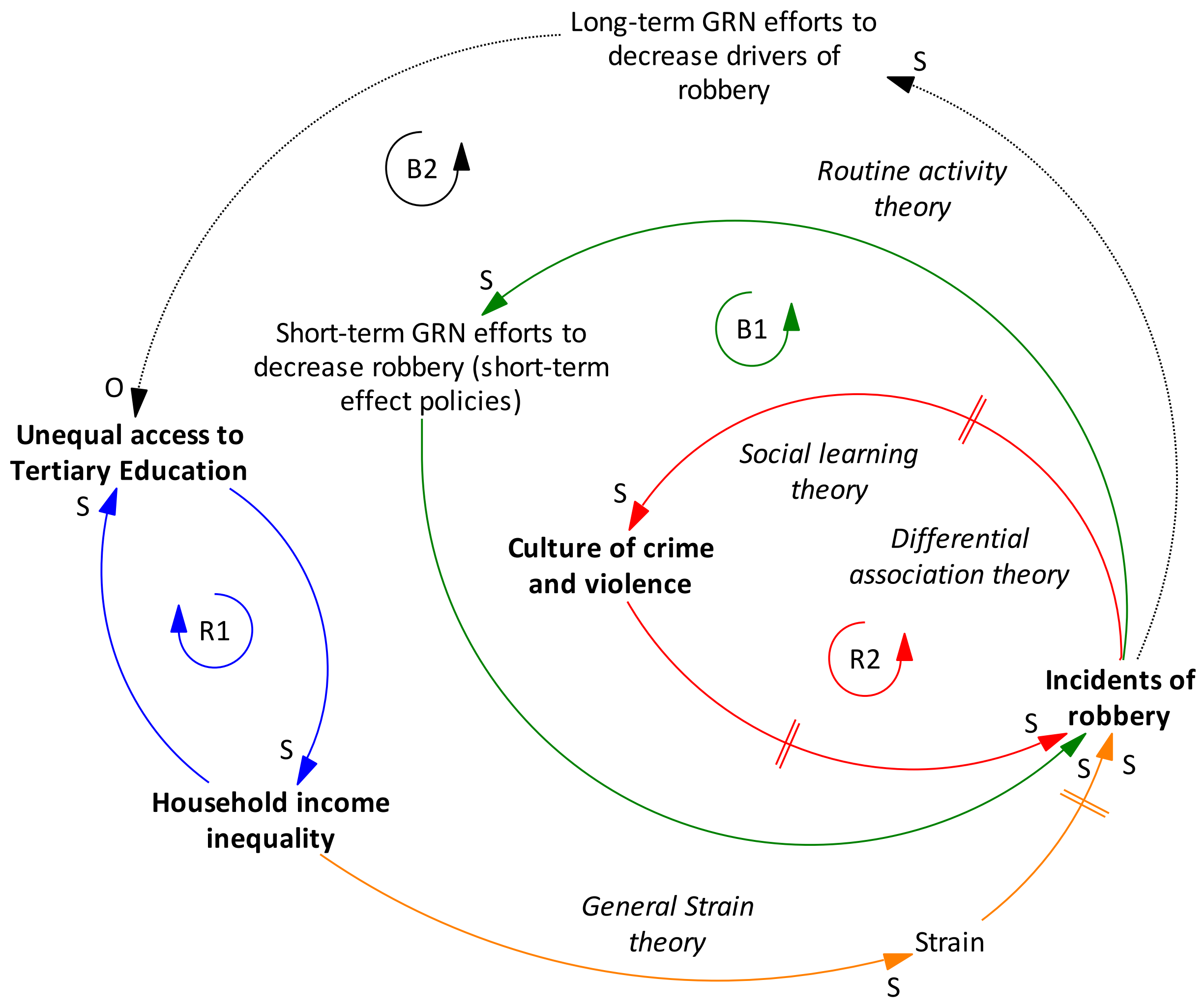

Figure 5.4: Dynamic hypothesis for drivers of robbery in the context of South African income- and education inequality

5.3 Stock and flow model

In system dynamics, explanations for phenomena are sought endogenously, meaning that they arise from within. Such a theory should create the dynamics of the system through the interaction of entities captured by the model. Therefore, the model structure and its decision rules should generate the problematic behaviour being investigated. Alterations of the model structure and decision rules may then be used to explore how the problematic behaviour may be changed through these alterations (Sterman, 2000: p. 95). This section aims to present the formal model that was developed to create system interactions, as shown in Figure 5.4. Firstly, a simplified overview of the entire model is provided. Then the model is described in more detail according the three sub-models that make up the entire model.

5.3.1 Structural overview

Figure 5.5 is a simplified representation of the entire stock and flow structure of the simulation model. *The first sub-structure*, which may be referred to as the *education structure*, represents populations of South Africans according to their highest level of education. Education levels range from 'less than primary complete' (LTPC) to 'tertiary education[19] completed' (TEC). Education levels that are lower

[19] As in the dynamic hypothesis, tertiary education in this case only consists of diplomas with Grade 12/ standard 10, bachelor's degrees, post-graduate diplomas and honours degrees. This constraint was implemented mainly due to information of NSC cohort progressions to higher education institutions being available only for the given degrees and diplomas.

than LTPC, such as pre-schooling and no education at all, were not accounted for. The structure accounts for population groups that are currently enrolled at primary-, secondary- and tertiary education institutions. The structure also accounts for population groups that have either completed a specific education level, or dropped out before completing a specific education level and discontinued any further learning.

The second structure, which may be referred to as the *income structure*, represents populations of South Africans according to their average monthly household incomes and is a co-flow of the education structure. The income levels of the five population stocks correspond to the income categories shown in Figure 5.3, where I1 represents the population with the lowest average monthly household income and I5 the population with the highest average monthly household income. The five inflows, labelled as 'progressions', are influenced by five outflows from the education structure according to ratios similar to those in Figure 4.6.

People may flow between income category stocks according to each stock's respective upward- and downward mobility rate. The structure accounts for deaths of the population through outflows at each income category stock. The income category stocks of the income structure influence two flows from the education structure and represent access to tertiary education through specific access ratios, similar to the ones shown in Table 4.2. This therefore creates the first reinforcing loop (R1) representing the relationship between tertiary education access inequality and household income inequality.

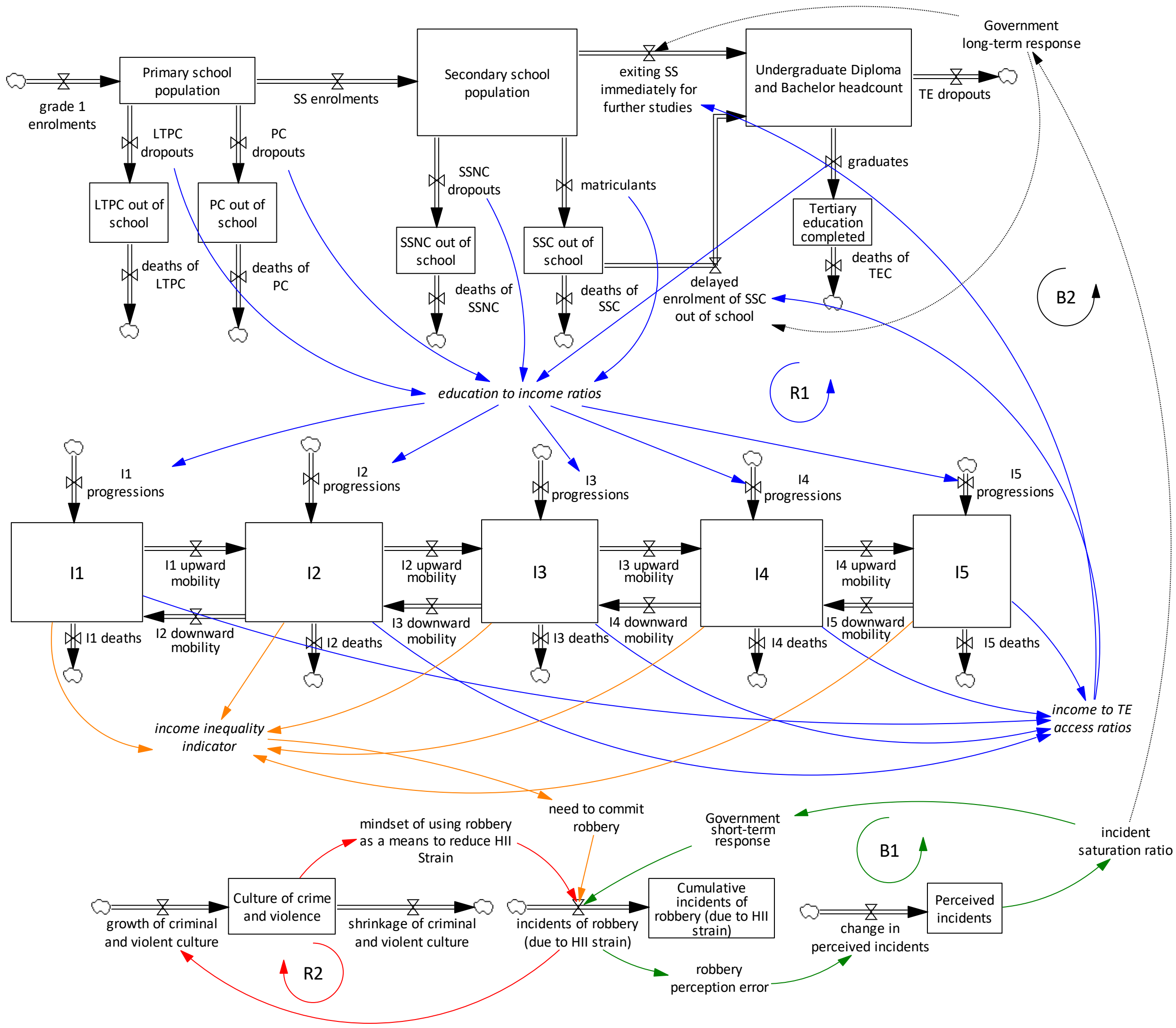

Figure 5.5: Simplified stock and flow structure of entire simulation model

The third sub-structure, which may be referred to as the *crime structure*, represents incidents of robbery due to household income inequality and the culture of crime and violence associated with it. The income structure influences the crime structure through an income inequality indicator that in turn effects the need to commit robbery, which then influences the flow of incidents of robbery due to household income inequality.

From this point, the second reinforcing loop (R2) emerges. Incidents of robbery due to household income inequality strain influence the flow representing the growth of the culture of crime and violence. The stock representing the level of the culture of crime and violence currently present in society effects the mindsets of individuals of the society regarding the use of robbery as a legitimate means to reduce the strain imposed on them due to household income inequality. This then returns to influence the flow representing incidents of robbery due to household income inequality and thereby completes the second reinforcing loop (R2).

From this point, the first balancing loop (B1) also emerges. In this loop, the government's short-term response to the current number of robbery incidents is delayed by a structure that distinguishes between the actual number- and the perceived number of robbery incidents. The government's response is then influenced by the perceived number of robbery incidents and affects the actual number of robbery incidents. This response is introduced as the degree to which the number of opportunities to commit robbery is reduced by the government and thereby closes the first balancing loop (B1).

The second balancing loop (B2) emerges from the incident saturation ratio. B2 represents long-term effect interventions introduced by the government to target drivers of robbery. In this study, these drivers are economic- and educational inequality. In the model this is defined as increased access to tertiary education for those who have obtained the NSC.

5.3.2 Education sub-model

For the education sub-model, a percentage of the entire South African (SA) population, as represented by the model shown in Figure 5.6, enrols in primary school each year. Figure 5.7 shows the stock and flow structure of the education sub-model. People enter the education sub-model at the primary school stage. People in the primary school population stock can obtain two final education levels: 1) less than primary complete (LTPC)[20] and 2) primary complete (PC)[21], or progress to secondary school. Both LTPC and PC population stocks have outflows representing deaths that have the same crude death rate as the South African population model.

People who have progressed to the secondary school population stock again can achieve two final education levels: 1) secondary school not complete (SSNC)[22] and 2) secondary school complete (SSC)[23], or progress to tertiary education the year immediately after completing Grade 12. The model does take into account that people from the SSNC and SSC stock may enrol for Adult Education and Training (AET) and Further Education and Training (FET). This is done through outflows from the SSNC and SSC stocks. The model does not deal further with those that go to AET- and FET centres, as this study focuses on tertiary education rather than further education. The inclusion of the AET and FET flows is solely for the purpose of increasing accuracy of the SSNC and SSC stock

[20] The LTPC stock refers to the population that enrolled for primary school, but never completed Grade 7. LTPC therefore refers to the population's final- and highest level of education.

[21] The PC stock refers to the population that enrolled for primary school, successfully completed Grade 7, but then ceased to progress to secondary school. PC therefore refers to the population's final- and highest level of education.

[22] The SSNC stock refers to the population that enrolled for secondary school, but never completed Grade 12. SSNC therefore refers to the population's final- and highest level of education.

[23] The SSC stock refers to the population that enrolled for secondary school, completed Grade 12, but did not immediately progress to tertiary education. SSNC therefore refers to a population of which some do go on to tertiary education after a certain time delay, but most keep the Grade 12 NSC as their final- and highest level of education.

populations. The model takes into account deaths occurring in the SSNC and SSC populations through the use of the crude death rate of the South African population model.

People may progress to the tertiary education[24] stock either the year immediately after obtaining the NSC (from the secondary school population stock) or after some time delay (from the SSC stock). The logic for determining immediate and delayed access to tertiary education will be discussed later in this sub-section. Once enrolled at a tertiary education institution, people may either move on to graduate level or drop out of the tertiary education system. People dropping out of a tertiary education institution go back to form part of the population that obtained the National Senior Certificate (Grade 12 completed) as their highest level of education. Those that graduate then form part of the population whose highest- and final level of education is at tertiary level. The model accounts for the deaths in this population through the use of the South African crude death rate. Appendix C1 may be consulted for a complete listing and description of all variables used to create the structure of the education sub-model.

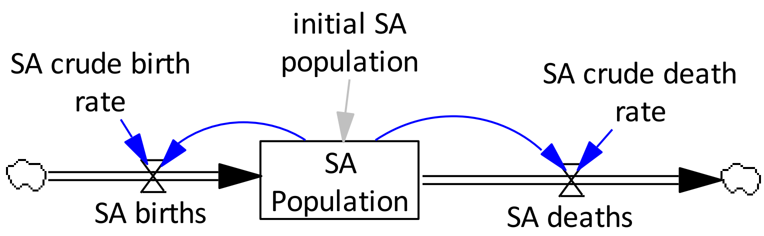

Figure 5.6: Stock and flow structure of simple South African population model

[24] Tertiary education, for this model, only refers to undergraduate degrees or diplomas that qualify as level 6, 7 or 8 of the South African National Qualifications Framework (NQF).

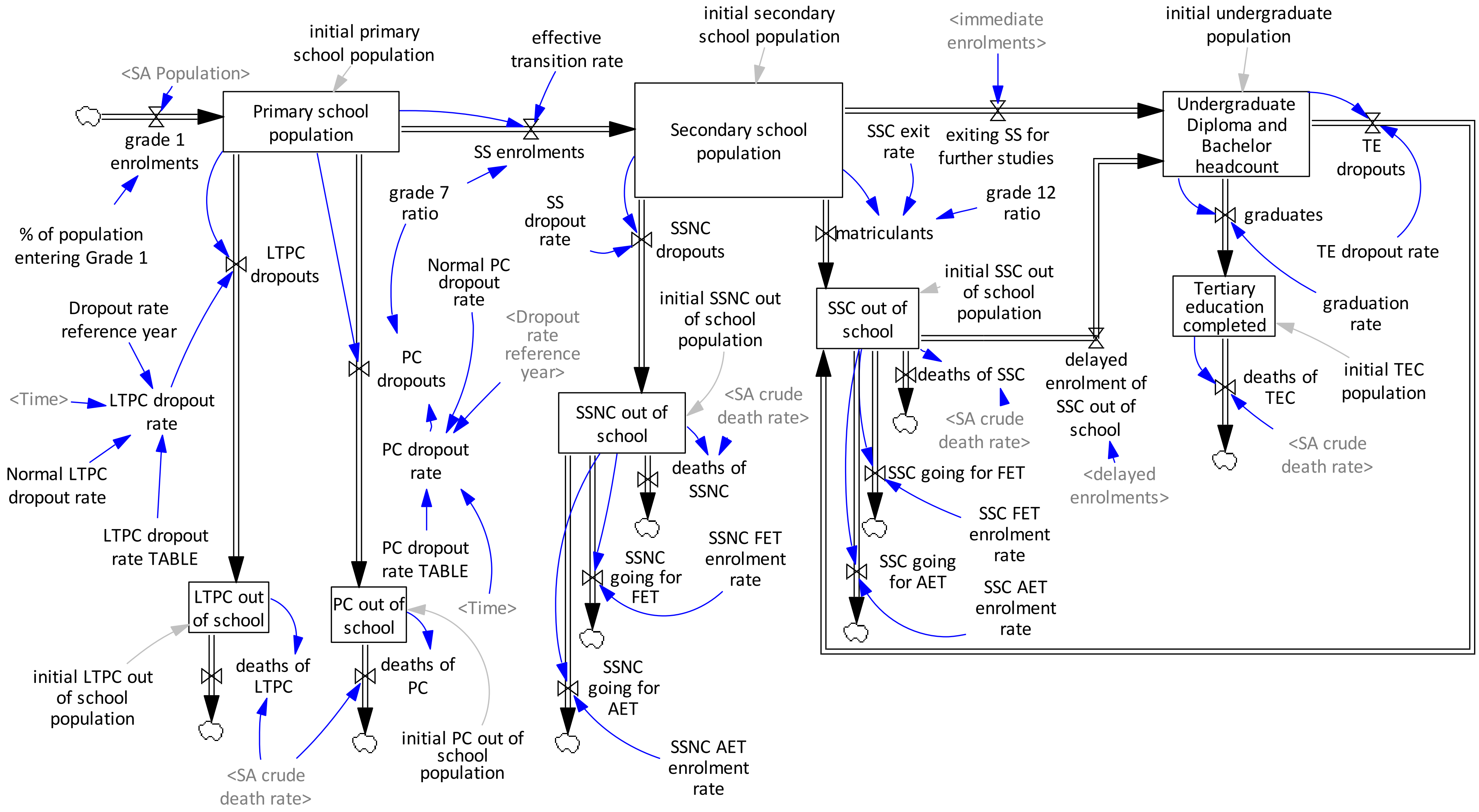

Figure 5.7: Stock and flow structure of education sub-model

5.3.3 Income sub-model

Figure 5.8 is a representation of the stock and flow structure of the income sub-model as a co-flow of the education sub-model. A co-flow may be used to represent attributes of the items that flow through a stock and flow structure (Sterman, 2000: p. 469). The income sub-model represents a co-flow of the education sub-model by representing average monthly household income categories of people in the population stocks labelled *LTPC out of school*, *PC out of school*, *SSNC out of school*, *SSC out of school* and *tertiary education completed*.

Each stock in this sub-model represents a population of South Africans that are not attending an educational institution, according to five average monthly household income categories. The stocks are labelled '*I1*' to '*I5*' according to their respective incomes. The income categories range from R0 – R4,999 per month to more than R20,000 per month and represent the income categories previously shown by Figure 5.3. The inflows of the stocks are called 'progressions' and represent a progression of people reaching their final level of education and therefore becoming part of the population that is not enrolled at any educational institution. The income category stocks therefore only account for people who are not attending any educational institution and have reached their final- and highest level of education. Each of these five inflows is influenced by five flows of the education sub-model ('*LTPC dropouts*', '*PC dropouts*', '*SSNC dropouts*', '*matriculants*' and '*graduates*') which represent people moving to their final level of education. These five flows create the five progression inflows, according to ratios similar to those shown in Figure 4.6 of the previous chapter. A brief explanation of the estimation of these ratios may be found in Appendix B3.

Additionally, this sub-model accounts for upward and downward mobility between the income category stocks according to each income category's respective upward and/or downward mobility rate. Using data generated from the National Income Dynamics Study (NIDS), Finn and Leibbrandt (2016) show the transitions of population groups they call 'poor' and 'non-poor' in South Africa. However, no literature currently exists on the transitions of population groups as specifically categorised by the model. Therefore, the mobility rates were estimated through model calibration to generate the best fit of the five income category stocks against their estimated reference modes.

Lastly, each of the five income category stocks deteriorate according to the South African population's crude death rate. Detailed descriptions of all variables used for the income sub-model may be found in Appendix C2.

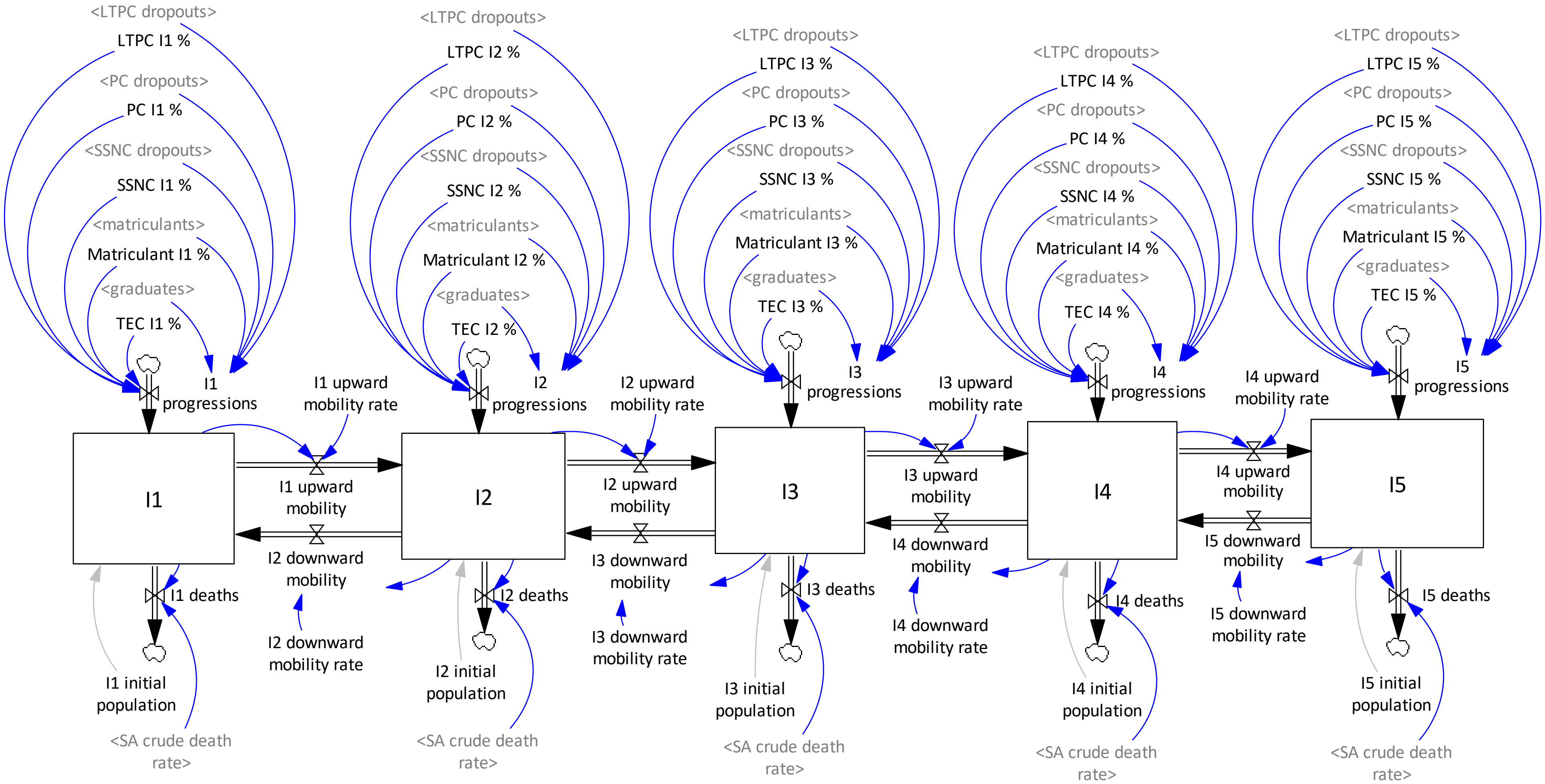

Figure 5.8: Stock and flow structure of income sub-model

As previously shown by Figure 5.5, the stocks of the income sub-model influence the immediate- and delayed tertiary education access rates of the education sub-model. Figure 5.9 represents the model's stock and flow structure that creates the influence of the income sub-model on the education sub-model. Shadow variables labelled *<I1>* to *<I5>* in grey represent the five population stocks of the income model. Variables labelled *i* to *v* in purple represent estimated preliminary[25] populations of Grade 12 learners of the current simulation year who are living in the households of the five income category populations of the income sub-model. Variables *i* and *v* represent preliminary Grade 12 learner populations that respectively live in households of the lowest- and highest income categories of the income sub-model. This did not account for each year's simulated Grade 12 population within secondary school which proved to create unrealistic behaviour when the model was subjected to extreme conditions. Therefore, each year's simulated *Grade 12 population*, taken as a percentage of the total secondary school population, was also used to calculate immediate- and delayed tertiary education enrolments.

Variables *I Grade 12* up to *V Grade 12* (in green) are used to adjust the preliminary Grade 12 populations and grouped into household income categories *i* to *v*, according to the current Grade 12 which is estimated as a percentage of the entire secondary school population. Involving the Grade 12 population size as a percentage of the entire secondary school population in the structure creates a more accurate representation of the immediate- and delayed tertiary education enrolments. Variables *i* to *v* are calculated as a percentage (*i%* to *v%*) of the respective household income category population. These percentages were derived from data collected by the 2009 General Household Survey (GHS). A brief explanation of the estimation of these percentages may be found in Appendix B4.

Figure 5.10 shows one to six year access rates for the 2008 to 2013 matric cohorts of South Africa as a percentage of all matriculants, as revealed from a study published in a working paper by Van Broekhuizen, van der Berg and Hofmeyr (2016: p. vi). The study used various South African datasets to estimate one-year to six-year university access rates for the 2008 to 2013 matric cohorts. The results reveal that 13% of the 2008 matric cohort accessed university within one year and that later enrolments decreased with each subsequent year. The model accounts for delayed enrolments according to the results of this study. Six variables, labelled *fa (im)* to *fa (d5)*, are used to account for people enrolling for tertiary education immediately, or those who delayed enrolment for up to five years after obtaining the NSC. Variables *ia% (im)* to *va% (im)* are used to account for immediate enrolment, whilst *ia% (d1)* to *va% (d5)* are used to account for the one- to five-year delays. To account for variable tertiary education access among different household income groups, each of these variables is influenced by variables *ia%* to *va%*, in red, representing university access rates according to ratios similar to those shown by Table 4.2 in the previous chapter. A brief explanation of the estimation of these ratios may be found in Appendix B5. These access rates are represented as being influenced by a long-term government response to levels of robbery. This influence will be discussed in the next sub-section relating to the crime sub-model.

Delays are then introduced as a fixed delay of between one and five years. This allows the researcher to separate the current matric cohort into immediate- and delayed tertiary education enrolments. These two variables determine the two flows that flow into the tertiary education population stock of the education sub-model and are shown as shadow variables in Figure 5.7. Descriptions of all variables used for the structure shown by Figure 5.9 may be found in Appendix C3.

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[25] Variables *i* to *v* represent preliminary estimations of Grade 12 populations according to income group. The estimations for these variables are preliminary, because they are only based on the sizes of the five income category stocks. The model adjusts these estimations with the estimated *Grade 12 population* size of each year, which is calculated as a percentage of the total secondary school population. This then yields variables *I Grade 12 – V Grade 12* (in green), which are more accurate representations of Grade 12 population sizes according to income group.

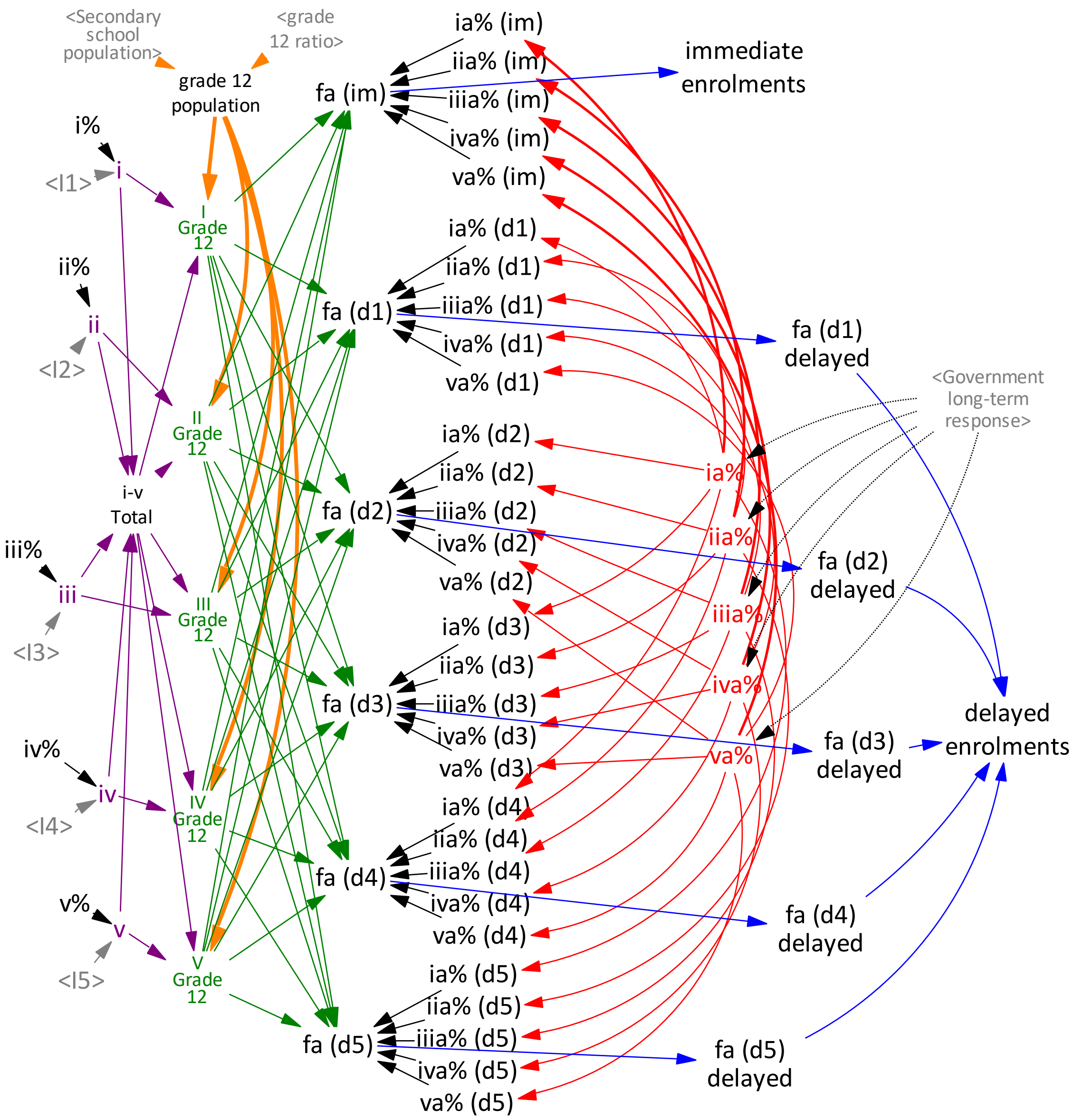

Figure 5.9: Stock and flow structure representing the influence of household income on tertiary education access rates

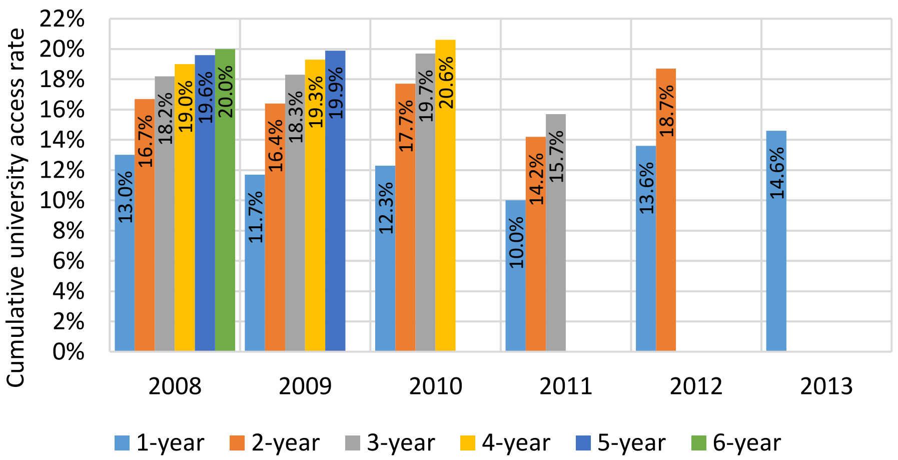

Figure 5.10: One to six year access rates for the 2008 to 2013 matric cohorts (% of matriculants) (Ammended from Van Broekhuizen, van der Berg & Hofmeyr, 2016: p. vi)

5.3.4 Crime sub-model

The final part of the model is formed by the crime sub-model. Firstly, the main structure of the crime sub-model will be described. Then, the income sub-model's influence on the crime sub-model will be discussed. Lastly, the influence of the crime sub-model on the education sub-model will be described.

Stock and flow structure of crime sub-model

The crime sub-model, shown in Figure 5.11, contains the second reinforcing loop (R2) and the first balancing loop (B1) of the simulation model.

General strain theory proposes that a wide range of stains or stressors increases the likelihood of crime (Agnew & Scheuerman, 2011). According to this theory, crime is a possible adaptation to stress whatever the source of stress (Akers, Sellers & Jennings, 2017: p. 196). As described by the Centre for the Study of Violence and Reconciliation (CSVR), inequality is one of the factors that sustains a culture of crime and violence in South Africa (CSVR, 2010: pp. 50-52).

As discussed in sub-section 4.2.5, empirical support for the relationship between inequality and crime has been found by several studies conducted in the United States of America (Danziger, 1976; Jacobs, 1981; Blau & Blau, 1982; Hsieh & Pugh, 1993; Kelly, 2000; Fajnzylber, Lederman & Loayza, 2002a; Lederman, Loayza & Menéndez, 2002). In addition to that, a study by Demombynes and Özler (2005) examined this relationship in the context of South Africa. Their results agree with sociological theories which argue that inequality leads to crime in general, and they also agree with economic theories that associate inequality with property crime. Therefore, income inequality may be regarded as one of the stressors, referred to by general strain theory, that increase the likelihood of robbery occurring in South Africa. Due to the model's purpose, this sub-model accounts for incidents of robbery due to household income inequality (HII) strain specifically and does not account for incidents of robbery due to other kinds of strain.

According to routine activity theory, a criminal act minimally requires three elements. These elements are 1) a potential offender, 2) a suitable target and 3) the absence of guardians that might prevent the act from occurring successfully (Cohen & Felson, 1979: p. 590). The flow representing *incidents of robbery (due to HII strain)* is a function that accounts for these three elements in a certain manner. This function uses the *need to commit robbery*, the *opportunity to commit robbery*, the *mindset of using robbery as a means to reduce HII strain* and the government's short-term response to generate the annual number of robbery incidents.

As mentioned previously, routine activity theory argues that the first required element for a criminal act is a potential offender. Attributes of such a potential offender are represented by two model variables. The first of these is the *need to commit robbery*, which is mainly driven by the level of income inequality in this model. As previously discussed in this sub-section, the crime sub-model ascribes the need to commit robbery to the argument of general strain theory, which states that a wide range of stains or stressors increases the likelihood of crime (Agnew & Scheuerman, 2011).

The second variable representing an attribute of a potential offender is the *mindset of using robbery as a means to reduce HII strain*. This attribute is based on differential association theory and social learning theory, both of which argue that criminal behaviour may be learned from the people that such a person associates with (Holt, 2009; Antwi Bosiakoh, 2012).

With regards to social learning theory, Akers (1999: pp. 64-66) argues that exposure to others' normative definitions favourable to illegal behaviour may lead a person to attaching a similarly favourable attitude to the same behaviour. More frequent and longer lasting exposure to such favourable attitudes towards illegal behaviour will have greater effects (Akers, 1999: p.64). This exposure to others' favourable attitudes towards crime and observance of their criminal behaviour may then lead to engagement in similar behaviour (Akers, 1999: p. 67).

An attempt was made to capture this concept in the model with the second reinforcing loop (R2). Each incident of robbery that occurs leads to a certain *growth of criminal and violent culture* in South African society. This represents a person's attachment of a favourable attitude towards illegal behaviour which has developed by the exposure to others' favourable attitudes towards crime, which are exhibited by their criminal acts. Therefore, more incidents of robbery lead to a greater growth of criminal and violent culture in the model.

The size of the *Culture of crime and violence* stock[26] in turn influences a potential offender's mindset of using robbery as a means to reduce the strain brought about by household income inequality. This mindset is defined as a ratio of the current *Culture of crime and violence* over the *maximum culture of crime and violence* that the society can attain. This means that as the culture of crime and violence increases, the mindset of using robbery to reduce strain (brought about by income inequality) also increases. This represents the argument of social learning theory that exposure to others' favourable attitudes towards crime, as well as an observance of their criminal behaviour, may lead to engagement in similar behaviour (Akers, 1999: p. 67).

This mindset variable influences the flow that represents incidents of robbery due to household income inequality. As the mindset variable is a ratio between 0 and 1, it means that as this mindset increase is influenced by increases in criminal and violent culture, which is brought about by increases in incidents of robbery, incidents of robbery increase. In short, this means that without any intervention increased incidents of robbery, due to household income inequality, lead to more incidents of the same crime. This thereby creates the second reinforcing loop (R2).

The model accounts for short- and long-term interventions by the government as a response to the number of annual robbery incidents. This part of the model is based on the adaptive expectations model as described by Sterman (2000: p. 428). In the introduction to information delays, Sterman (2000: p. 426) describes that various delays exist in channels of information feedback. An example of this may be the measurement or perception of a variable. Perceptions involve delays, because such beliefs are based on information available to the decision-maker at the time. As time to gather information is needed prior to forming judgements, it means that decisions are often made with information about the past (Sterman, 2000: p. 426).

For this model, it is assumed that governing authorities responsible for short-term and long-term robbery reduction are not notified of incidents of robbery as soon as they occur but are rather provided this information after a time delay. Therefore, governing authorities use delayed information to make decisions, which may be referred to as *perceived incidents* of robbery. This means that an error exists between current actual incidents of robbery and currently perceived incidents of robbery. As new information of robbery incidents become available, governing authorities can compare their perceptions of robbery to delayed actual incidents of robbery and adjust their perceptions accordingly.

For both balancing loops (B1 & B2), these perceived incidents of robbery are used to determine a response to the currently perceived situation. The first balancing loop (B1) is a short-term response that is aimed at reducing the *opportunity to commit robbery*, which in turn decreases the number of robberies occurring. Such a response may take the form of increased police visibility. Therefore, this may be regarded as a strategy that targets the third essential element of a criminal act: the absence of guardians to intervene (Cohen & Felson, 1979: p. 590).

The second balancing loop (B2) represents a long-term response that is aimed at increasing the tertiary education access rates of the education sub-model, as shown in Figure 5.9. This response is intended to reduce a person's motivation to commit robbery – caused by the strain produced by income inequality – by reducing income inequality through increased tertiary education access. This approach may be regarded as targeting the first essential element of a criminal act: a potential offender (Cohen & Felson, 1979: p. 590). Descriptions of all variables used for the crime sub-model may be found in Appendix C4.

[26] It is assumed that as time passes, past criminal events gradually fade from people's minds as they forget about them. Therefore, this stock is decreased according to the *culture fade time*. The outflow of this stock is basically defined as (culture stock)/(culture fade time).

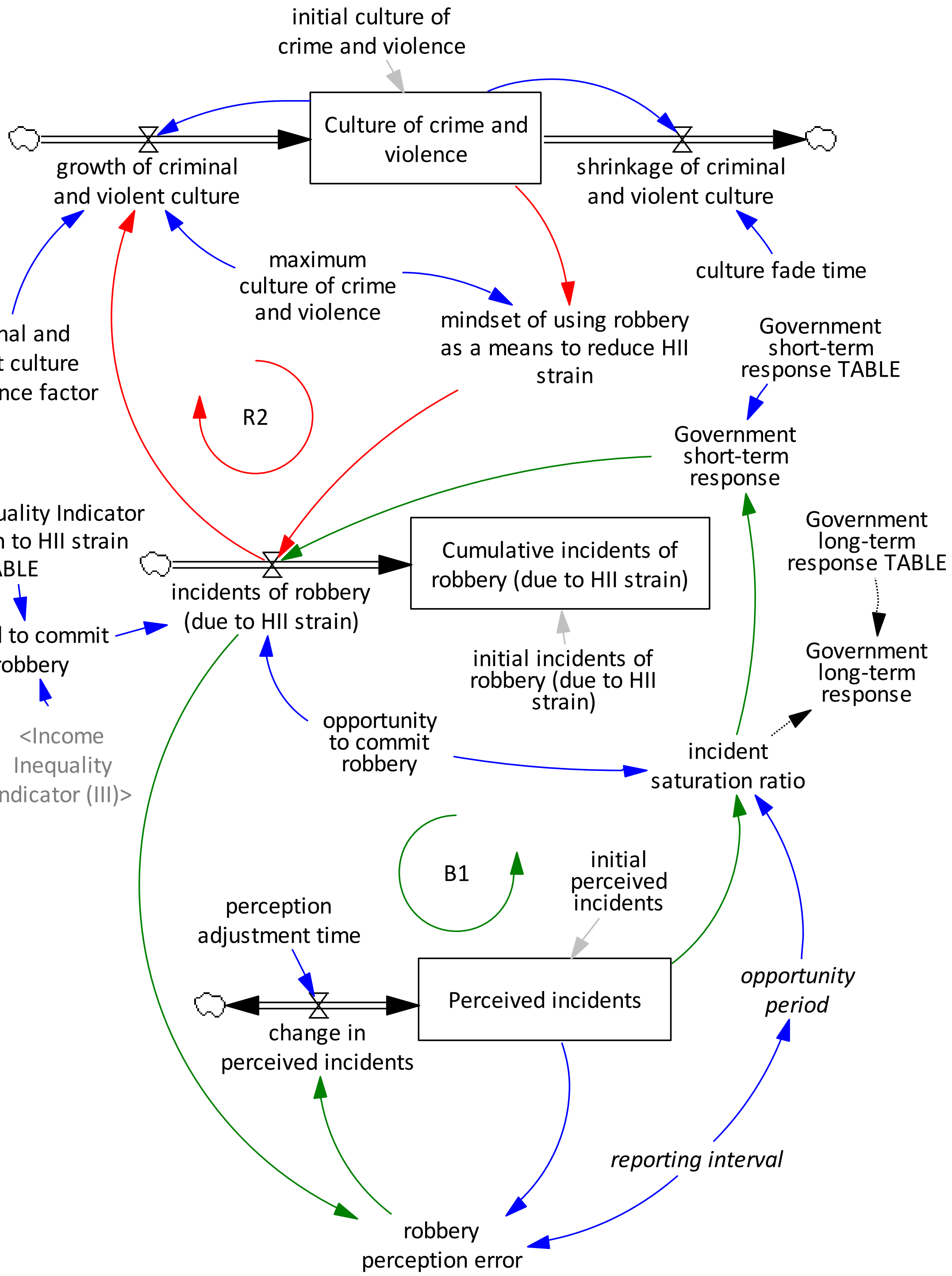

Figure 5.11: Stock and flow structure of the crime sub-model

Calculation of the Income Inequality Indicator (III)

To calculate the *need to commit robbery* the crime sub-model requires an Income Inequality Indicator (III) and this is calculated from the five household income category populations of the income sub-model. This III is calculated according to a method by which the Gini coefficient may be estimated. As mentioned in sub-section 4.1.2, the Gini coefficient is a measure of unequal income distribution. The coefficient ranges from zero to one, where a higher Gini coefficient means more income inequality and vice versa. The coefficient approaches one when a single person, within the population N, earns all the income, while the remaining (N-1) inhabitants earn nothing (Kalmijn, 2014).

The Lorenz curve is a graphical measure of income- or wealth distribution developed by the American economist Max Otto Lorenz (1905). An example of a Lorenz curve may be seen in Figure 5.12. The Lorenz curve is composed of data that relates the cumulative proportion of the population to its respective cumulative proportion of income (Lorenz, 1905). Consider the example shown in Figure 5.12. The 45-degree line in orange represents perfect equality on the Lorenz curve. For income, this would mean that every person in the population receives the same income. The curved blue line represents deviation from perfect equality. From this Lorenz curve, it can be read that the poorest 70% of the population receive only 30% of the total cumulative income. The curve also indicates that the poorest 90% of the population receive around 65% of the total cumulative income. This means that the richest 10% of the population receive 35% of the total cumulative income.

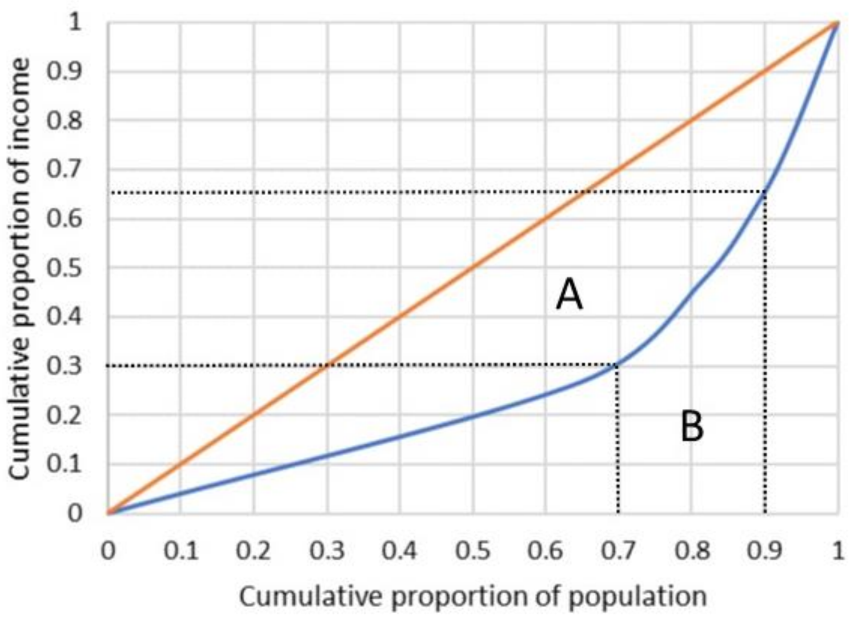

Figure 5.12: Example of a Lorenz curve

The Gini coefficient may be estimated from the Lorenz curve as the ratio of two areas created by the curve. The first area (A) is between the orange 45-degree line and the blue Lorenz curve. The second area (B) is the area below the Lorenz curve. With these two areas, the Gini coefficient may be defined as A/(A+B). Using the trapezium rule, the Gini coefficient may be estimated with the following equation (Sun *et al.*, 2010: p. 602):

$$\text{Gini} = 1 - \sum_{k=1}^{n} (\mathrm{X}_k - X_{k-1})(Y_k + Y_{k-1}) \tag{1}$$

For the simulation model of this study, an Income Inequality Indicator (III) was calculated from the five income category populations of the income sub-model by first performing calculations to create a Lorenz curve, and then estimating the Income Inequality Indicator (III) from the Lorenz curve by using Equation (1). It should be noted that the III calculated by the model should not be compared to the South African Gini coefficient shown in Figure 4.4. This is due to two reasons. Firstly, it should be noted that there are various approaches to calculating the Gini coefficient (Abounoori & McCloughan, 2003: p. 505). It is not clear which method was used to calculate the Gini coefficient shown in Figure 4.4. Therefore, it is possible that the Gini coefficient shown in Figure 4.4 is not estimated according to Equation (1).

Secondly and more importantly, the structure of the model only allows for a crude estimation of income inequality. The model only accounts for five income categories, in R5,000 intervals, with the highest income category allowing for an infinite range. More and smaller ranges of income categories would generate a more accurate representation of income inequality. The model structure is restricted to five income categories to keep the model simple. The highest income category already begins at R20,000 due to the limited upper income ranges generated by the General Household Surveys (GHS) conducted between 2009 and 2017. The limitations of the Income Inequality Indicator (III) calculated by the model should therefore be kept in mind when interpreting the model's results.

Figure 5.13 shows the stock and flow structure used to calculate points necessary to plot the Lorenz curve. Firstly, cumulative proportions of households in South Africa are calculated from the five household income categories of the income sub-model. The cumulative household proportions are used as the x-coordinates for the Lorenz curve. Then, cumulative proportions of monthly household incomes are calculated to generate the y-coordinates for the Lorenz curve. Figure 5.14 shows the stock and flow structure used to calculate the Income Inequality Indicator (III) from the generated Lorenz curve coordinates. The structure shown in Figure 5.14 estimates the III according to Equation (1) with n=5. Descriptions of all variables used to calculate the Lorenz curve points, as well as its corresponding III estimation, may be found in Appendix C5.

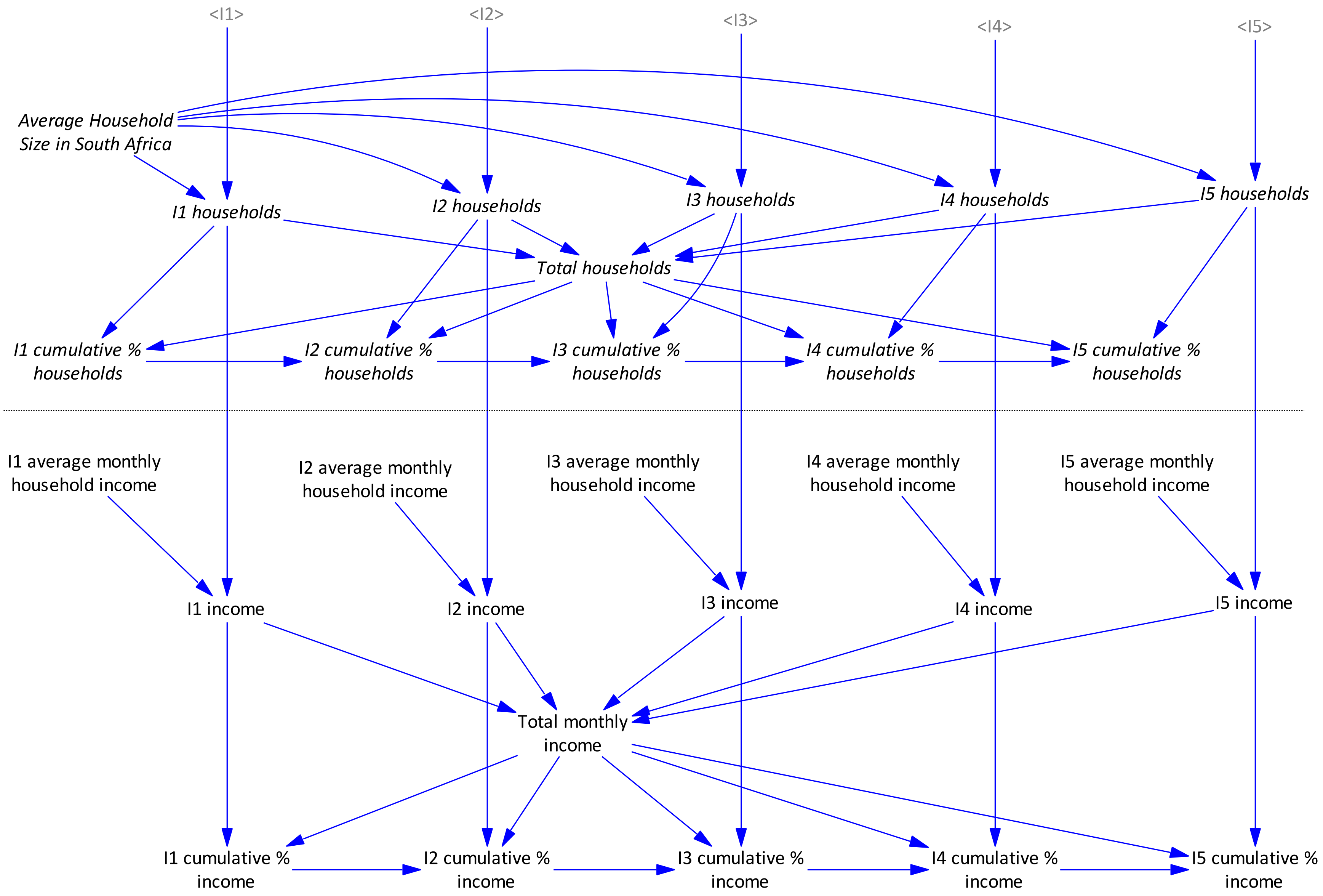

Figure 5.13: Stock and flow structure for Lorenz curve calculations

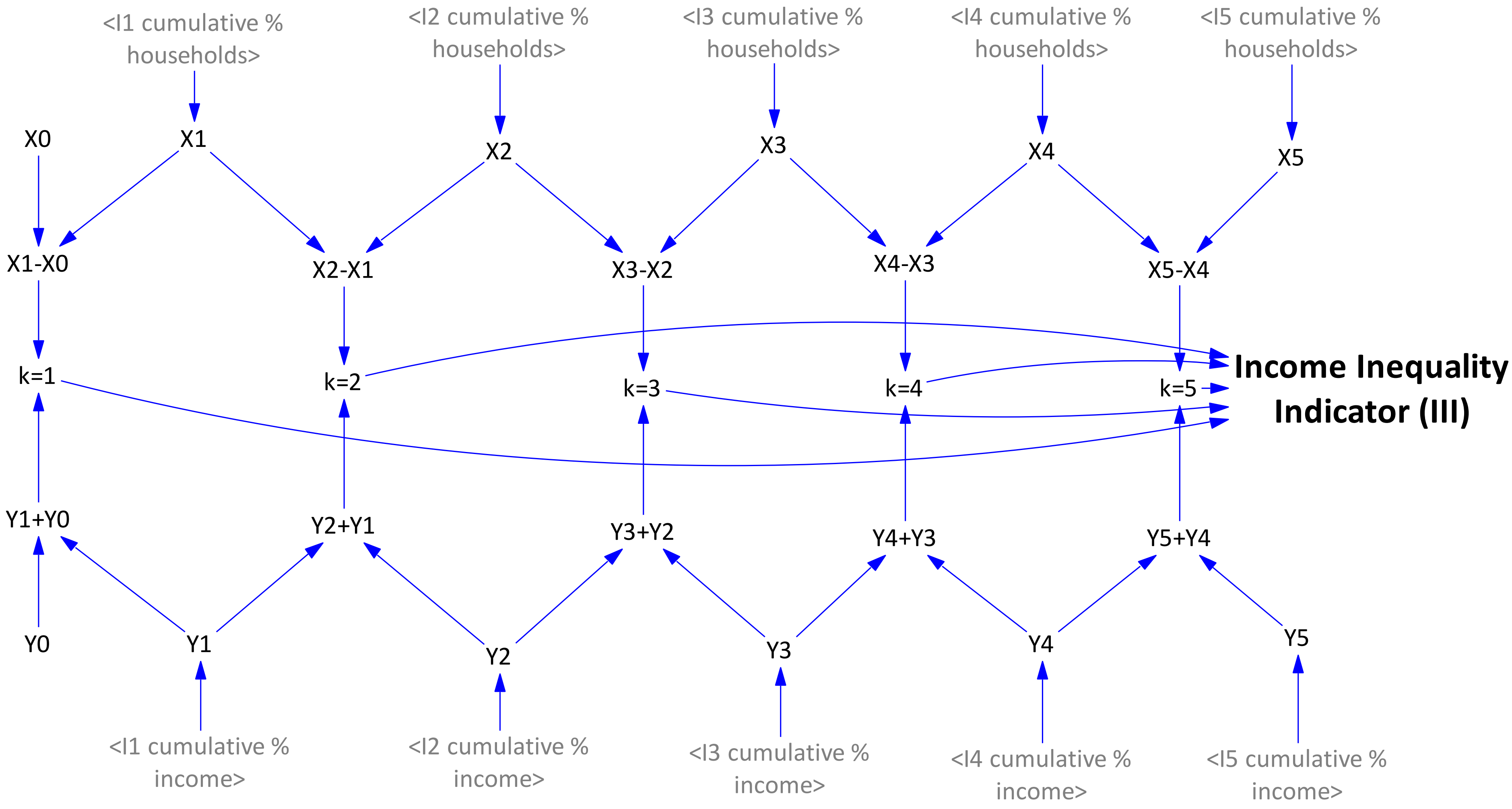

Figure 5.14: Stock and flow structure for estimating the Income Inequality Indicator (III) from the Lorenz curve coordinates

5.3.5 Assumptions

Multiple assumptions have been made to simplify the simulation model. Some of these assumptions are mentioned in the boundary adequacy test and the structure assessment test. This sub-section provides short lists of core assumptions made for each of the sub-models.

Although the model is defined at a national aggregation level, the model does not account for the entire South African population. This is due to the fact that only people with certain education levels were accounted for. This assumption was made to simplify the model. The short list of core assumptions made for the education sub-model may be found in Table 5.1.

Table 5.1: Short list of core assumptions made for the education sub-model

Assumption	Description
All South Africans undergo some form of education during their lifetimes.	For the model it is assumed that all South Africans will enrol at school and have at least enrolled for Grade 1 during their lifetimes. Therefore, people with no schooling were excluded from the education sub-model. This assumption was made from the data provided by the 2012 Quarterly Labour Force Survey. From this dataset it may be seen that only a small proportion of South Africans do not undergo any education during their lives (Statistics South Africa, 2012). Figure 9.2 of Appendix B1 provides a visual representation of this observation.
Learner neighbourhood wealth quintiles can be directly associated with school wealth quintiles	This assumption was made due to the findings provided by Zoch (2017: p. 12,37). These findings, shown earlier in Table 4.3 of sub-section 4.1.3, provide an indication that learner neighbourhood wealth quintiles are strongly associated with school wealth quintiles in South Africa. Although the results do not show a direct correlation, the association was deemed strong enough to assume a direct correlation.
Tertiary education only refers to undergraduate degrees and diplomas of NQF levels 6, 7 and 8.	This assumption was made to simplify the model. Accounting for postgraduate degrees would require more complexity. Other undergraduate degrees and diplomas were not accounted for due to the lack of available data.
People do not take up any further education if they have dropped out of primary- or secondary school.	Although possible, the re-enrolment into primary- and secondary school of people who have dropped out of the schooling system before completing Grade 12 seemed negligible. Therefore this was excluded from the model.

The general assumption for the income sub-model is that the rates which govern the flows of the model remain constant throughout the simulation. Although data from the General Household Surveys (GHS) and the study by Finn and Leibbrandt (2016: p. 6) show that in reality these rates vary over time, such accuracy seemed unnecessary for the purpose of the model. Additionally, only very few factors were allowed to influence the income levels of South Africans. This assumption focused on the relationship between inequality of access to tertiary education and income inequality. Table 5.2 represents the short list of core assumptions made for the income sub-model.

Table 5.2: Short list of core assumptions made for the income sub-model

Assumption	Description
Ratios influencing progressions from the education sub-model to the income co-flow are constant.	Data from the General Household Surveys (GHS) conducted between 2009 and 2018 show that these ratios vary over time in reality (Statistics South Africa, 2013b, 2013c, 2013d, 2013e, 2014a, 2016a, 2017a, 2018a, 2018b, 2019). However, the ratios were assumed to be constant because the derivation[27] of these values showed that they only vary slightly over the period between 2009 and 2018.

[27] A brief discussion on the derivation of these ratio may be seen in Appendix B3.

Upward- and downward mobility rates are constant.	As shown by the study of Finn and Leibbrandt (2016: p. 6), upward and downward economic mobility rates also vary over time in South Africa. The trends of populations living in households according to the five discussed income groups are unique, as they have been derived[28] for this study specifically. Therefore, no research regarding the mobility of people between these specific income categories exists. For this reason, the mobility rates were estimated as constants through calibration of the model.
Only deaths, upward- and downward mobility rates and education levels influence the five income category populations.	As shown by Woolard and Klasen (2004: p. 18), various other factors, such as employment status and changes in labour earnings, have an influence on the income levels of South African households. These other factors were excluded from the model because the model focuses on the relationship between education levels and household income levels in South Africa.

As mentioned before, the study by the Centre for the Study of Violence and Reconciliation (CSVR) revealed that various factors sustain the culture of crime and violence in South Africa and therefore contribute to violent crime (CSVR, 2010: pp. 50-52). The crime sub-model, however, only focuses on incidents of robbery that are committed due to strain developed by household income inequality, as well as the relationship between these robberies and the culture of crime and violence in South Africa. Therefore, various other factors that may influence individual components of this sub-model have been excluded. The short list of core assumptions made for the education sub-model may be found in Table 5.3.

Table 5.3: Short list of core assumptions made for the crime sub-model

Assumption	Description
Some robberies only occur because of the strain caused by household income inequality.	General strain theory argues that a variety of factors may act as strains which increase the likelihood that an individual will commit crime (Agnew & Scheuerman, 2011). The crime sub-model only accounts for robberies that occur due to the strain caused by household income inequality. Robberies that occur due to other types of strain or combinations of strains were not accounted for, as these robberies are outside the model boundary.
The culture of crime and violence in South Africa is only sustained due to incidents of robbery.	As discussed in sub-section 4.1.1, it is argued that various factors sustain the culture of crime and violence in South Africa (CSVR, 2010: pp. 50-52). This study specifically focuses on the influence of education- and income inequality on robbery which in turn influences the culture of crime and violence in South Africa. Therefore, other factors influencing the culture of crime and violence in South Africa were excluded from the model.
The number of opportunities to commit robbery within a specific period of time remains constant.	Various factors may influence the potential number of robberies that may occur within a certain time-period. Place-based theories such as crime pattern theory, social disorganisation theory and environmental criminology theory, as mentioned in sub-section 4.2.2, have a strong focus on these potential opportunities (Verma & Lodha, 2002; Rengifo, 2009; Brantingham, 2010). Such influences, however, are beyond the scope of this study.
Underreporting of incidents of robbery is excluded.	Demombynes and Özler (2005: p. 283) demonstrate that underreporting of incidents of robbery in South Africa is significant. This factor was excluded from the model for the sake of simplicity.
Short-term and long-term government responses to crime levels occur after a time delay.	Various delays exist in channels of information feedback (Sterman, 2000: p. 426). It is assumed that the reporting of robbery incidents and the response to current levels of robbery may be referred to as information feedback channels. Therefore, the first balancing loop (B1) is based on the adaptive expectations model as described by Sterman (2000: p. 428) to account for an information time delay.

[28] A brief discussion on the derivation of these trends may be seen in Appendix B2.

5.3.6 Model settings

The simulation model was developed with Vensim DSS. The time horizon was specified from 2008 until 2130 as described in sub-section 5.1.3. A time step of 0.0078125 was chosen together with the Euler integration method. The choice of time step and integration method will be further discussed in the integration error test sub-section. Annual time units were specified, because most of the available data and information for the model is only available in yearly intervals. The model settings regarding time bounds, as specified in Vensim DSS, are shown in Figure 5.15.

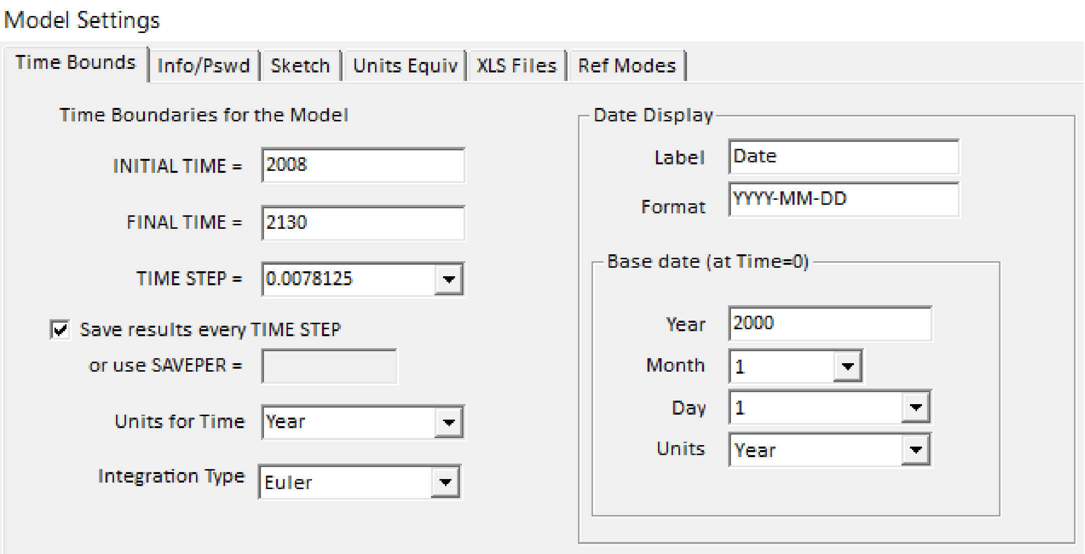

Figure 5.15: Model settings specified in Vensim DSS

5.4 Model testing

A large part of the remaining modelling process, from the point of having a dynamic hypothesis, helps to test and improve the dynamic hypothesis (Sterman, 2000: p. 95). Modelers speak of 'validating' models, but this is in essence impossible because 'all models are wrong'. Validity implies support by objective truth. All models are merely simplified representations of the real world, and therefore differ from reality in many ways (Sterman, 2000: p. 846). Therefore, model validation is impossible. Instead, one is able to test the model. The model testing process allows one to uncover flaws, understand the model's limitations, and ultimately build confidence that the model is appropriate for its intended purpose (Sterman, 2000: pp. 845-846). This section tests the simulation model according to eight tests suggested by Sterman (2000: pp. 858-861).

5.4.1 Boundary adequacy

The boundary adequacy test determines whether the model boundary is appropriate for the model's purpose (Sterman, 2000: p. 861). The system dynamics methodology uses various tools to convey the model boundary and present its causal structure. One of these is the model boundary chart, which sums up the model scope by stating which variables were used endogenously, exogenously, or were completely excluded from the model (Sterman, 2000: p. 97). To determine the adequacy of the model's boundary, model boundary charts were constructed for each sub-model. The number of excluded concepts and variables is of course infinite (Sterman, 2000: p. 861). A variable or concept that is modelled exogenously already implies that all factors influencing that variable or concept have been excluded from the model. The excluded column lists concepts and variables that, if included, might have considerable impact on policy decisions given the model's purpose (Sterman, 2000: p. 861).

5.4.1.1 Education sub-model

The model boundary chart developed for the education sub-model is represented by Table 5.4. A significant simplification is imposed by accounting for only undergraduate degrees and diplomas of NQF levels 6, 7 and 8 obtained from South African universities at the tertiary education level. The education sub-model also does not account for people who have not obtained any education. The effect of the quality of education offered at all educational institutions on dropout rates is also ignored. Additionally, the effects of early childhood development on educational attainment are not accounted for.

Table 5.4: Model boundary chart for education sub-model

Endogenous	Exogenous	Excluded
• Grade 1 enrolments • Primary school population • Primary school pupils dropping out before completing Grade 7 • Population, not enrolled in any educational institution, whose highest- and final level of education is less than Grade 7 • Deaths of people forming part of populations that are not enrolled in an educational institution • Primary school pupils dropping out of the school system after completing Grade 7 • Population, not enrolled in any educational institution, whose highest- and final level of education is Grade 7 • Secondary school enrolments • Secondary school population • Secondary school pupils dropping out before completing Grade 12 • Population, not enrolled in any educational institution, whose highest- and final level of education is less than Grade 12 • Enrolments for AET and FET after either dropping out of- or completing secondary school • The flow representing matriculants moving to an intermediate state population where some will continue to tertiary education, while most will not • Population, not enrolled in any educational institution, whose highest- and partially final level of education is Grade 12 • Population, not enrolled in any educational institution, whose highest- and partially final level of education is Grade 12 • Matriculants immediately enrolling at tertiary education institutions • Matriculants delaying enrolment at tertiary education institutions for up to 5 years • Population enrolled at tertiary education institutions for undergraduate degrees and diplomas of NQF levels 6, 7 and 8	• Percentage of total South African population entering Grade 1 annually • Normal dropout rates of primary school pupils • Percentage of primary school population that is in grade 7 • Transition rate from primary school to secondary school • Dropout rate of secondary school pupils • AET and FET enrolment rates • Percentage of secondary school population that is in grade 12 • Percentage of Grade 12 population that does not immediately continue to tertiary education • Dropout rate for students enrolled at tertiary education institutions for undergraduate degrees and diplomas of NQF levels 6, 7 and 8 • Graduation rate of students studying undergraduate degrees and diplomas of NQF levels 6, 7 and 8 • Crude South African birth rate • Crude South African death rate • Percentages governing the delay of enrolment for matriculants from households with differing incomes, which do access tertiary education within five years of matriculation	• Tertiary education other than undergraduate degrees and diplomas equivalent to NQF levels 6, 7 and 8 • People without any level of education • Quality of education offered at educational institutions • The effect of early childhood development on dropout and educational attainment

• Students dropping out of undergraduate degrees and diplomas of NQF levels 6, 7 and 8 • Graduations of students studying undergraduate degrees and diplomas of NQF levels 6, 7 and 8 • Population, not enrolled in any educational institution, whose highest- and final level of education is an undergraduate degree or diploma of NQF level 6, 7 or 8 • Births in South Africa • Deaths in South Africa • South African population • Tertiary education access rates for matriculants from households with different incomes		

5.4.1.2 Income sub-model

The model boundary chart developed for the education sub-model is represented by Table 5.5. A crucial assumption made for the income sub-model is the exclusion of availability of jobs related to the education levels accounted for. The relation of education level to income level is achieved through ratios calculated from data obtained by the General Household Surveys conducted between 2009 and 2018 (Statistics South Africa, 2013b, 2013c, 2013d, 2013e, 2014a, 2016a, 2017a, 2018a, 2018b, 2019). Another important assumption is the exclusion of employment- and unemployment levels. Regardless of an individual's level of education, the model does not consider their employment status. Additionally, the influence of Adult Education and Training (AET) and Further Education and Training (FET) on household income is not accounted for. AET and FET enrolments were only included in the education sub-model to increase the accuracy of the population stocks representing people who have either matriculated and delayed tertiary education, or dropped out of secondary school before completing Grade 12. Furthermore, as the education sub-model only accounts for certain tertiary qualifications, the income sub-model is also simplified in this manner.

Table 5.5: Model boundary chart for income sub-model

Endogenous	Exogenous	Excluded
• Flows representing progressions into the various household income categories • Populations representing people not attending any educational institution according to five income categories • Upward- and downward mobility of people between the five income category populations • Deaths of people in the five income category populations	• Ratios determining the distribution of progressions of people with various education levels into different income category populations • Upward- and downward mobility rates of flows between the five income category populations • South African crude death rate	• Availability of jobs affecting people's earning capability • Employment- and unemployment levels • Influence of populations with AET and FET qualifications on household income levels • Influence of other tertiary qualifications, besides those named, on income levels

5.4.1.3 Crime sub-model

Table 5.6 represents the model boundary developed for the robbery sub-model. This study focusses on robbery specifically; therefore other types of crime have been excluded from the model. Additionally, this study does not consider the impact of other types of strain on the occurrence of robbery, apart from strain due to household income inequality. As discussed in Chapter 4, many other factors sustain the culture of crime and violence in South Africa (CSVR, 2010: p. 50). However, for this study, inequality – specifically income inequality and unequal access to tertiary education – is accounted for. As argued by various criminological theories, other factors besides the level of culture of crime and violence in the society affect an individual's decision-making process regarding the act of committing robbery (Verma & Lodha, 2002; Holt, 2009; Rengifo, 2009; Wikström, 2009; Wright, 2009; Agnew & Scheuerman, 2011; Antwi Bosiakoh, 2012; Garoupa, 2014). These other factors have been excluded from the model. Reporting error was also omitted from the model. Data from the Victims of Crime Survey of 1998 revealed that robbery in South Africa exhibited the lowest reporting rate at 42%, while 95% of car theft was reported (Demombynes & Özler, 2005: p. 283). This factor was also excluded from the model.

Table 5.6: Model boundary chart for robbery sub-model

Endogenous	Exogenous	Excluded
• Income Inequality Indicator (III) • The need to commit robbery due to household income inequality • Incidents of robbery due to household income inequality • Level of criminal and violent culture present in the South African society • Growth and decay of South African culture of crime and violence • Mindset of people regarding the use of robbery as a means of reducing the strain imposed by household income inequality • Difference between actual incidents of robbery and perceived number of robbery incidents • Adjustment between perceived and actual incidents of robbery • Perceived number of robbery incidents • Ratio of actual- over possible incidents of robbery • Short-term government response to number of robberies occurring • Long-term government response to number of robberies occurring	• Maximum strain attainable due to income inequality • Relation of the Income Inequality Indicator (III) to strain due to household income inequality • Factor determining the sustaining effect that incidents of robbery have on the culture of crime and violence • Maximum culture of crime and violence attainable in the society • Time required for present culture of crime and violence to fade from society • Number of opportunities to commit robbery in a year • Time interval between robbery incident reports • Time needed to adjust robbery incident perception error • Time available for robbery incidents to occur • Relation of number of robberies to short-term government response • Relation of number of robberies to long-term government response	• Other types of crime influenced by strain due to household income inequality • Impact of other types of strain on the occurrence of robbery • Other factors influencing the culture of crime and violence in the society • Additional factors influencing an individual's mindset regarding the act of committing robbery (e.g. rational choice theory) • Reporting error influencing the authorities' perceptions regarding robbery incidents

5.4.1.4 Boundary adequacy test conclusion

The model boundary went through several iterations as it was presented to criminologists, economists, and system dynamics experts throughout the development of the model. Appendix D may be consulted for iterations of the model boundary in the form of causal loop diagrams, the interview guide used for semi-structured interviews, as well as the written consent form developed for ethical clearance. After several iterations and considering the constraints for the study, the model boundary was deemed as adequate for the model purpose. As the model represents a dynamic hypothesis, the model boundary is open for change if the model were to be developed further.

5.4.2 Structure assessment

The structure assessment test evaluates the model's consistency in representing the system using relevant descriptive knowledge of the system, according to the model purpose (Sterman, 2000: p. 863). The structure of the simulation model was assessed according to level of aggregation, conformance to basic physical realities and the logic of the decision rules.

Entire simulation model:
The simulation model is presented at national level. This means that a very simplified version of the system is presented and does not account for differences among provinces, municipal areas, towns and suburbs. A lower aggregate level would create a more accurate representation of the real system. This simplification was applied due to the unavailability of data at lower aggregate levels. An advantage of the high aggregation level used is the ability to look at the system as a whole as opposed to its smaller parts. For all sub-models it was verified that stocks cannot become negative and that matter is conserved in the system.

Education sub-model:
One simplification of the education sub-model is the aggregation of education levels. The model may provide more insights when individual grades and degree/diploma types are accounted for. The influence of foreign nationals is another factor that was excluded. Foreign nationals come to South Africa to study, work and reside. This does have an influence on the attained education levels, as well on as the populations of those currently enrolled at educational institutions (Crush & McDonald, 2000). It was assumed that this would have little effect on the overall system and was thus excluded. The possibility of South Africans being educated through the educational institutions of other countries was also not accounted for.

Income sub-model:
A critical limitation of the income sub-model is the aggregation of income categories. The income categories aggregate incomes into R5,000 intervals. The last category has the largest range, ranging from R20,000 to a theoretical infinity. A lower aggregation, especially for the highest income category would yield a better approximation of the Income Inequality Indicator (III) derived from the five income category levels. The income sub-model does not allow people to bypass a specific income category. Every person that exhibits upward- or downward mobility can only pass through the income categories sequentially, without bypassing any. This was not taken into account, because the income categories are at a fairly high aggregate level.

Crime sub-model:
As mentioned in the boundary adequacy test, the crime sub-model only accounts for robbery committed due to strain caused by household income inequality. This therefore creates a narrow focus for the implications on crime, as it is the purpose of the model.

Furthermore, decision-making regarding criminal behaviour is a highly complex process with various views on what influences this process, as can be observed by the brief list of various criminological theories previously presented by Table 4.4 in sub-section 4.2.2. However, the crime sub-model only considers two factors: strain created by income inequality, and the culture of crime and violence. The decision-making process for committing robbery presented by this sub-model is therefore highly simplified. Due to the complex nature of criminal behaviour the researcher admits that the crime sub-model exhibits many inadequacies regarding the decision-making process for incidents of robbery.

Additionally, the crime sub-model represents the concept of criminal and violent culture in South Africa in a highly simplified manner. In reality, criminal and violent culture develops, accumulates, and decays in a far more complex way (Glaser, 2008). The model was kept simple to achieve a basic overview of the factors related to the purpose of the model.

The same applies to the manner in which government authorities respond to the level of crime. The short- and long-term response strategies of the South African government are far greater in number and more diverse than those depicted by the model (Du Plessis & Louw, 2005). The responses were simplified to represent high level differences brought about by short- and long-term crime prevention strategies.

Considering this sub-section’s discussion regarding the level of aggregation, conformance to basic physical realities and the logic of the decision rules, it was concluded that the model shows adequate consistency in representing the system by using relevant descriptive knowledge of the system according to the model purpose. As all dynamic hypotheses may evolve, the limitations of the model structure discussed above may be addressed if the model is developed further.

5.4.3 Dimensional consistency

For a system dynamics model, all equations should be dimensionally consistent without using any factors that have no real-world meaning (Sterman, 2000: p. 866). It was ensured that the equations of the simulation model were dimensionally consistent by continually using the automated dimensional analysis function of Vensim DSS and by manually inspecting the equations. Appendix C contains all equations of the simulation model, along with their associated units.

5.4.4 Parameter assessment

Before estimating any parameters, it must be ensured that parameters have a real-world meaning (Sterman, 2000: pp. 866-867). This approach was followed, as advised by Sterman. After ensuring that all parameters have a real-world meaning, parameters were estimated. Throughout the development of the simulation model parameters were estimated from literature, judgement and datasets. Sterman (2000: pp. 855-856) argued that a system dynamics simulation model should be fully replicable to improve the transparency of the model and therefore allow others to continue building on the existing model. For this reason, a complete description of the model as well as brief descriptions of parameter estimations may be found in Appendix C.

5.4.5 Extreme conditions

A simulation model should be robust in extreme conditions. This means that the model should behave realistically even when subjected to unlikely conditions (Sterman, 2000: p. 869). Extreme condition tests may be formulated to test whether the model conforms to basic physical laws (Sterman, 2000: p. 860). Several extreme condition tests have been performed to evaluate whether the model behaves realistically. What follows is a description of the most important extreme condition tests performed.

5.4.5.1 Education sub-model

For the first extreme conditions test of the education sub-model, Grade 1 enrolment since 2008 was reduced to zero. It was expected that the primary school population would gradually drop towards zero. This means that all other stocks in the education sub-model would eventually decrease as the number of people in the system decreased due to constant death rates. The test revealed that the model behaved as expected, as may be partially seen in Figure 5.16.

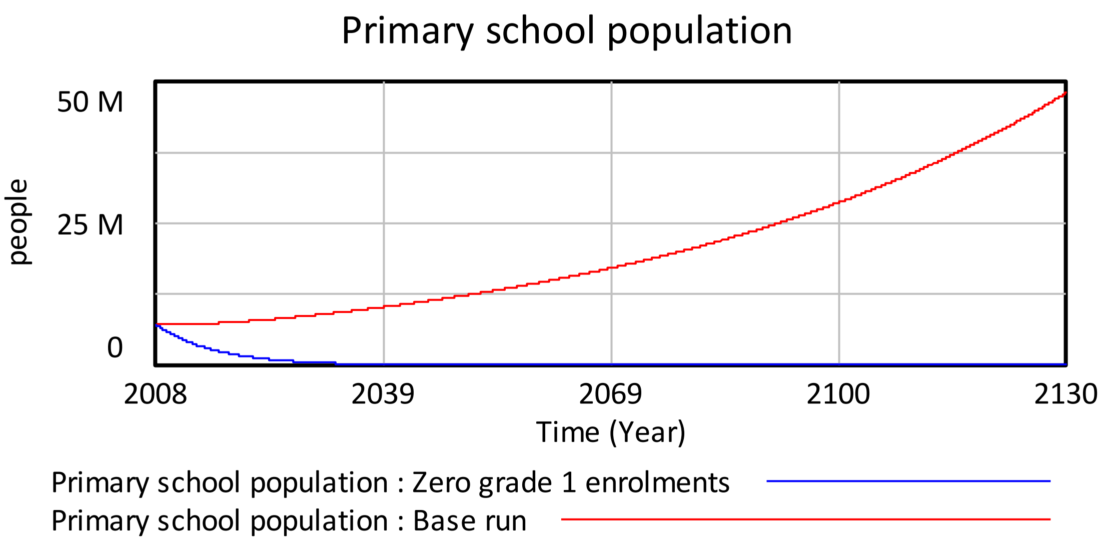

Figure 5.16: Simulation results of primary school population stock for extreme condition Test 1 of the education sub-model

For the second extreme conditions test of the education sub-model, the secondary school dropout rate since 2008 was increased to 100%. It was expected that the 100% dropout rate at secondary school would initially cause a drop in population size and then sustain a population size far lower than under normal circumstances. The parts of the system upstream from this point should not be affected. The *SSNC out of school* stock should experience a sudden and sustained increase far higher than under usual conditions, because of the increased flow rate. The other three stocks downstream from the secondary school population should exhibit a decreased population size, as their flows depend on the secondary school population stock size. The test revealed that the model behaved as expected, as may be partially seen in Figure 5.17.

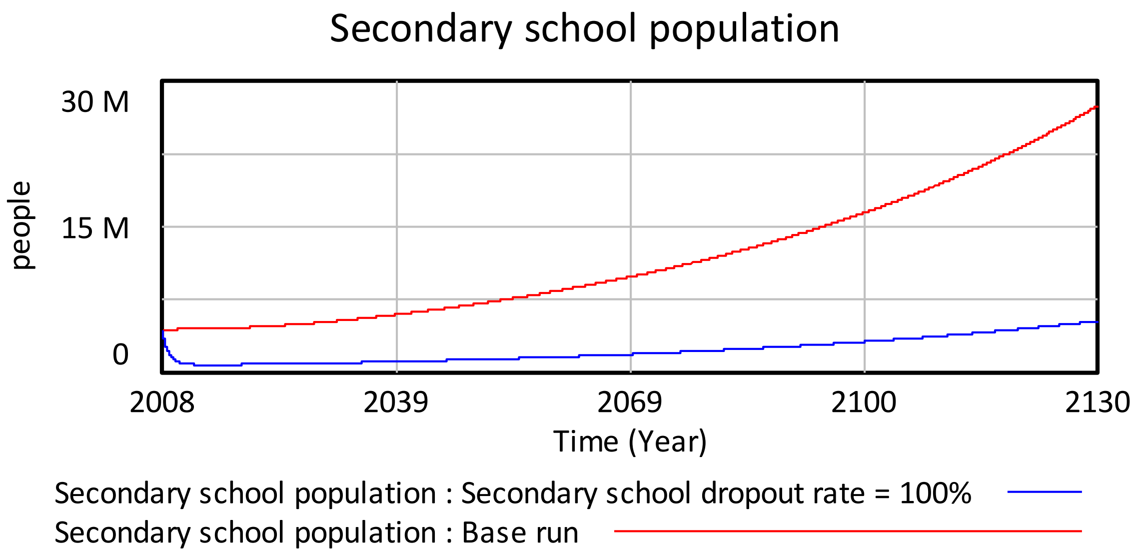

Figure 5.17: Simulation results of secondary school population stock for extreme condition Test 2 of the education sub-model

For the third extreme conditions test of the education sub-model, deaths accounted for by the education sub-model since 2008 were eliminated. It was expected that the stocks representing people in primary- and secondary education institutions would not be affected by this test. The stock representing people in tertiary education institutions might be slightly increased, as it received an inflow from the *SSC out of school* stock. The population stocks representing populations according to their final- and highest level of education should experience populations larger than under normal circumstances. The test revealed that the model behaved as expected, as may be partially seen in Figure 5.18.

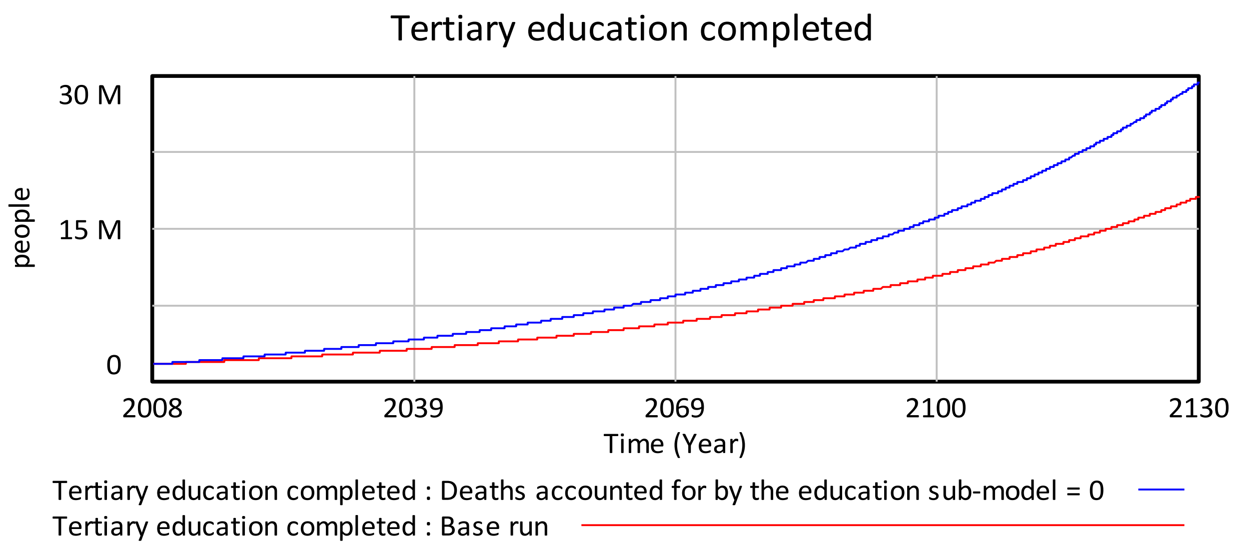

Figure 5.18: Simulation results of 'Tertiary education completed' stock for extreme condition Test 3 of the education sub-model

5.4.5.2 Income sub-model

For the first extreme conditions test of the income sub-model, all upward mobility rates since 2008 were increased to 100%. It was expected that the population stocks *I1* up to *I4* would decrease sequentially as each stock reached a new equilibrium and finally levelled out. Population stock *I5* should initially increase dramatically as the other stocks reached their new equilibrium conditions. After the system reached a new equilibrium, the *I5* stock should continue to gradually increase. The test revealed that the model behaved as expected, as can be observed in Figure 5.19.

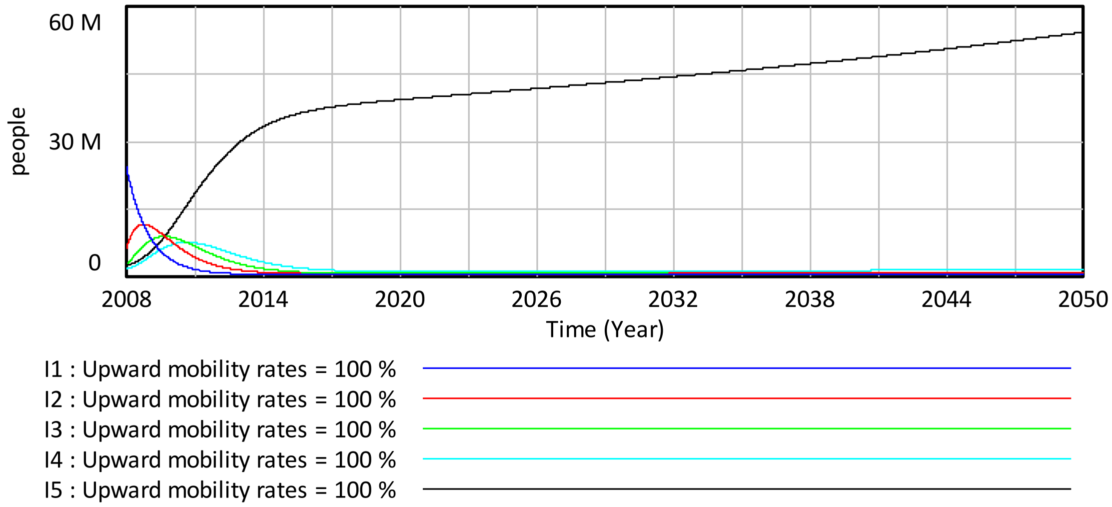

Figure 5.19: Simulation results of stocks I1-I5 for extreme condition Test 1

For the second extreme conditions test of the income sub-model, all downward mobility rates since 2008 were increased to 100%. It was expected that the population stocks *I2* up to *I5* would decrease sequentially, as each stock reached a new equilibrium, and finally levelled out. Population stock *I1* should initially increase dramatically as the other stocks reached their new equilibrium conditions. After the system reached a new equilibrium, the *I1* stock should continue increasing gradually. The test revealed that the model behaved as expected, as can be observed in Figure 5.20.

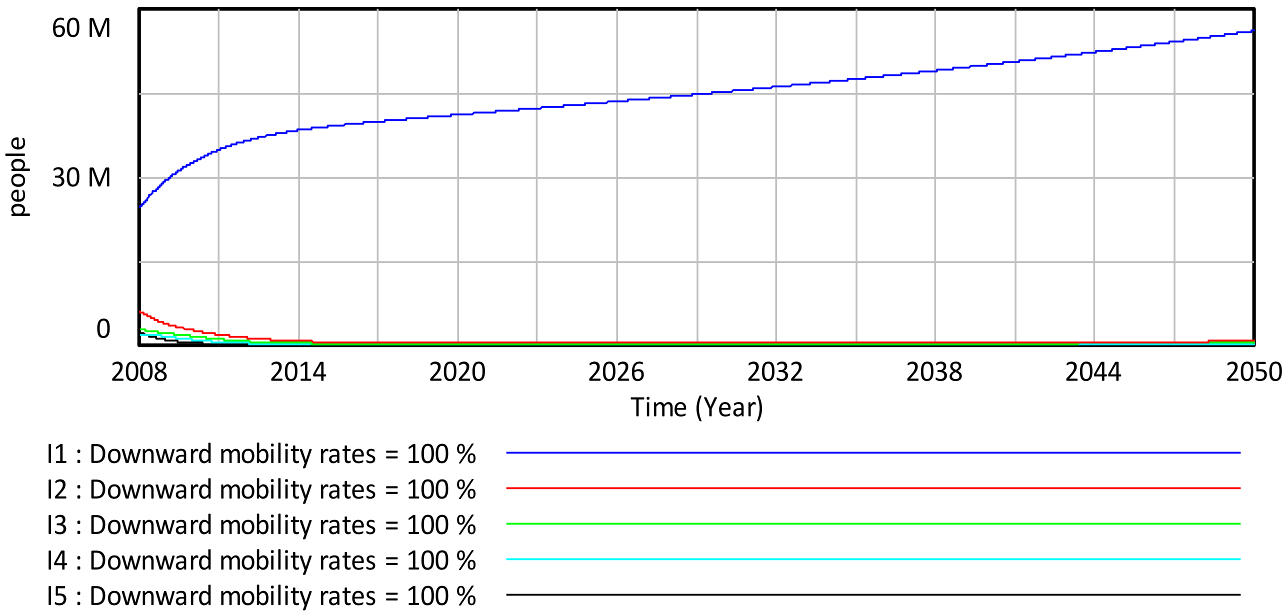

Figure 5.20: Simulation results of stocks I1-I5 for extreme condition Test 2

For the third extreme conditions test of the income sub-model, progression inflows since 2008 were decreased to zero. It was expected that the five population stocks would decay gradually. This behaviour should result because the stocks of the income sub-model only experienced outflows and no inflows in this test. The test revealed that the model behaved as expected, as can be partially observed in Figure 5.21.

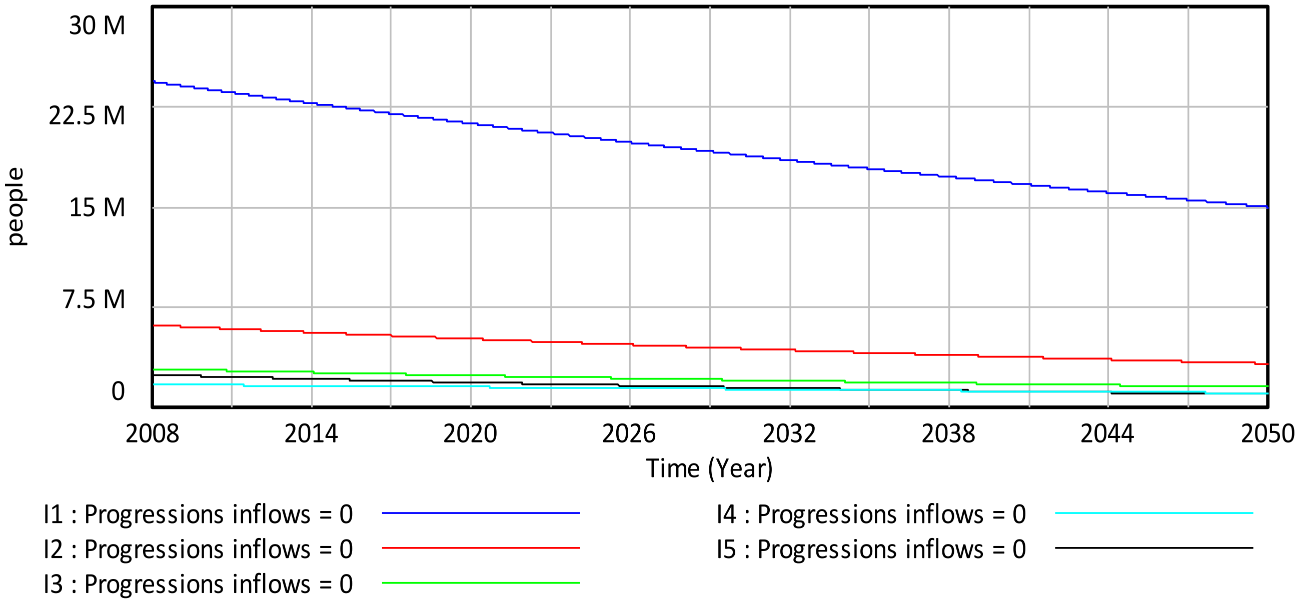

Figure 5.21: Simulation results of stocks I1-I5 for extreme condition Test 3 of the income sub-model

5.4.5.3 Crime sub-model

For the first extreme conditions test of the crime sub-model, *culture fade time* since 2008 was increased to 1000 years. It was expected that increasing the *culture fade time* would decrease the flow that shrinks criminal and violent culture. This should cause the *Culture of crime and violence* stock to grow more than usual. A more prominent culture of crime and violence should then lead to an increase of incidents of robbery. The test revealed that the model behaved as expected, as can be partially observed in Figure 5.22.

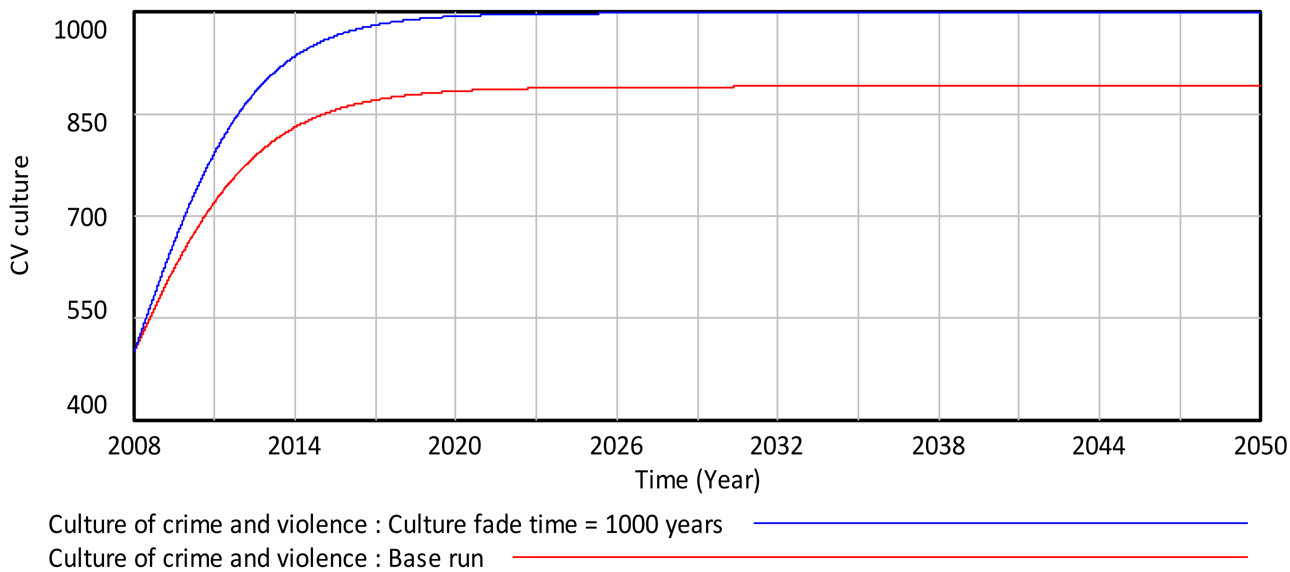

Figure 5.22: Simulation results of crime and violence culture stock for extreme condition Test 1 of the crime sub-model

For the second extreme conditions test of the crime sub-model, the *opportunity to commit robbery* since 2008 was reduced to 0.0000001. It was expected that reducing the opportunities to commit robbery to almost zero would reduce incidents of robbery to a very low number. This in turn should lead to a decay of the crime and violence culture stock. The test revealed that the model behaved as expected, as can be partially observed in Figure 5.23.

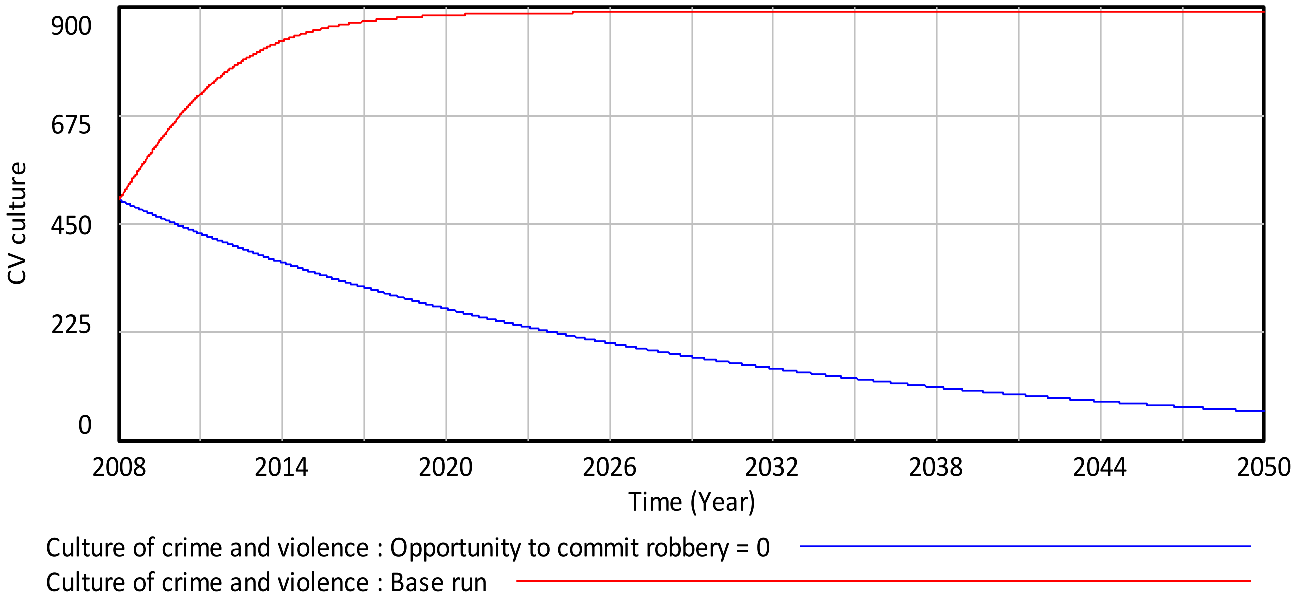

Figure 5.23: Simulation results of crime and violence culture stock for extreme condition Test 2 of the crime sub-model

For the third extreme conditions test of the crime sub-model, perception adjustment time since 2008 was increased to 1000 years. It was expected that this large increase in perception adjustment time would create a large lag in government response to the current incidents of robbery. This would therefore allow for more incidents of robbery than under normal conditions. More incidents of robbery would then result in a higher level of criminal and violent culture. The test revealed that the model behaved as expected, as can be partially observed in Figure 5.24.

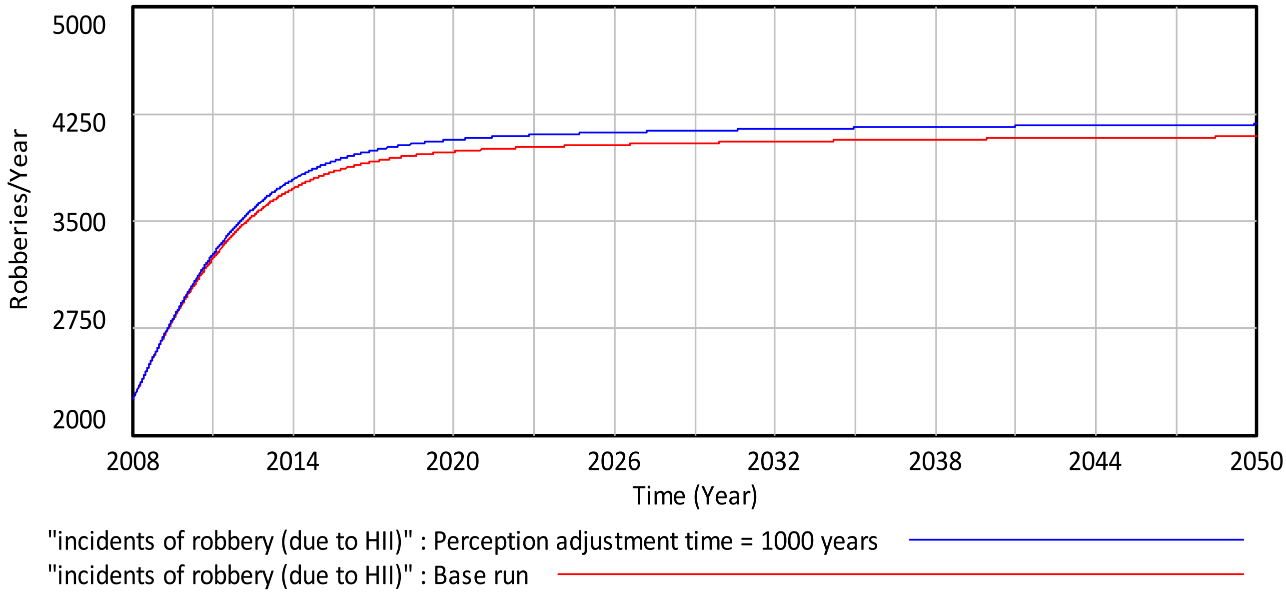

Figure 5.24: Simulation results of incidents of robbery flow for extreme condition Test 3 of the crime sub-model

5.4.5.4 Extreme conditions test conclusion

The model was exposed to extreme conditions as discussed in this sub-section. Any inadequacies identified during these tests were addressed in order to produce the realistic behaviour shown. Therefore, the model was considered to be robust to extreme conditions.

5.4.6 Integration error

For system dynamics modelling, one should select a time step and an integration method that results in an estimation of the system's underlying continuous dynamics which is precise enough for the model's intended purpose. If the simulation results change significantly when halving the time step, then the time step is too large and a smaller time step should be selected. Halving the time step should be continued until the model results are no longer sensitive to the selection of time step Sterman (2000: p. 872).

Initially, a time step of 1 was used. Halving the time step revealed that the key variables of the model were sensitive to the time step. The timestep was then reduced to 0.0078125, and halving the time step again to yield 0.00390625 resulted in insignificant changes of simulation results. The insensitivity of the Income Inequality Indicator (III), one of the key variables in the system, towards this reduction in time step is shown in Figure 5.25. With a time step of 0.0078125[29], the model's sensitivity to integration method was tested. The model results showed no sensitivity to the choice of integration method at time step 0.0078125. This is presented visually in Figure 5.26.

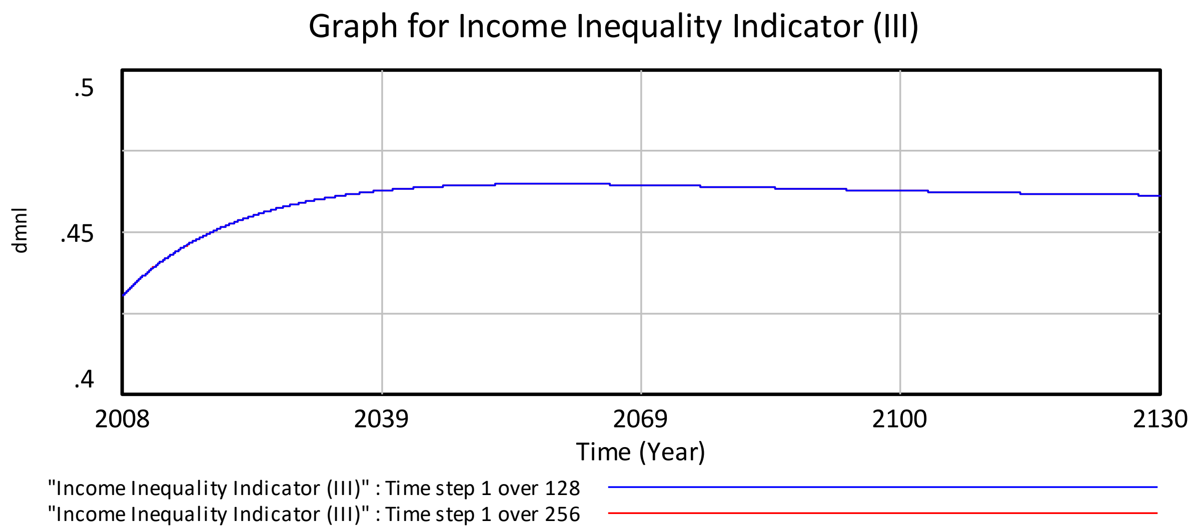

Figure 5.25: Income Inequality Indicator's (III), insensitivity to reduction of time step from 0.0078125 to 0.00390625

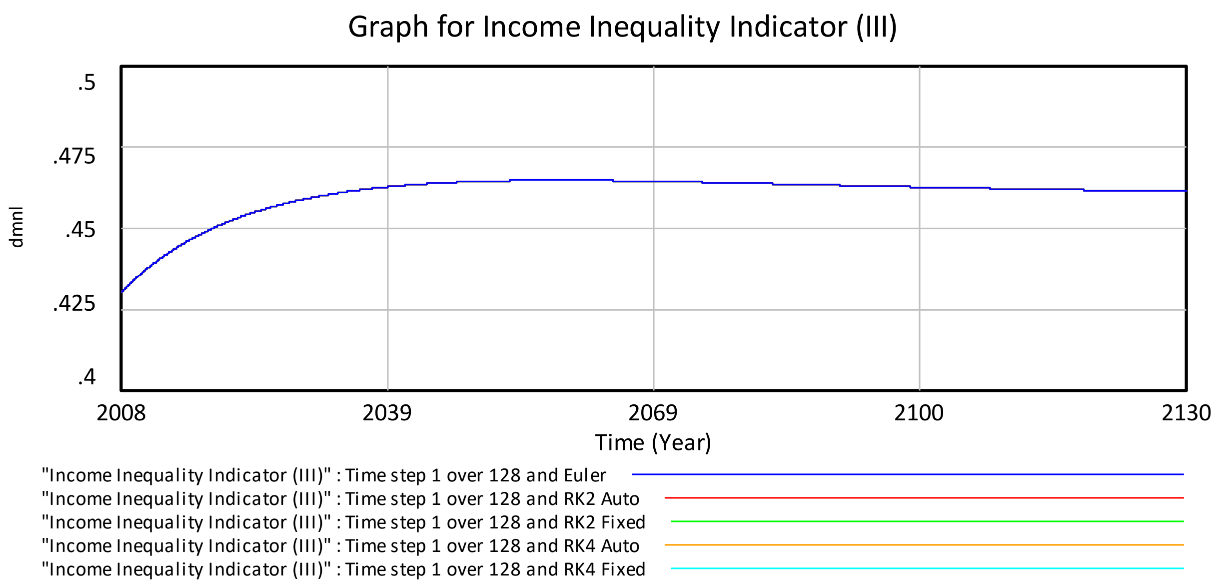

Figure 5.26: Income Inequality Indicator's (III) insensitivity to the choice of integration method at time step 0.0078125

[29] The fraction 1/128 yields 0.0078125. This is indicated in the results as '1 over 128'.

5.4.7 Behaviour reproduction

Sterman (2000: p. 860) provides quantitative as well as qualitative methods to perform the behaviour reproduction test. For this study, only qualitative methods of behaviour reproduction testing were applied. The simple qualitative behaviour reproduction test used for this study involved visually comparing results of certain variables of the simulation to real world data. The simulation results should show substantial similarity to the real world data to pass this test.

5.4.7.1 Education sub-model

The simulation model was calibrated in an attempt to fit the real-world data as appropriately as possible by using a plausible range of parameter variations. From the following figures it may be observed how the simulation results compare to real world data, as well as estimated reference modes.

Figure 5.27 shows the real-world data[30] of the *primary school population* in blue and the simulation results in red. From the graph it can be observed that the simulation results generally fit the real-world data. The simulation model has been calibrated to achieve this fit.

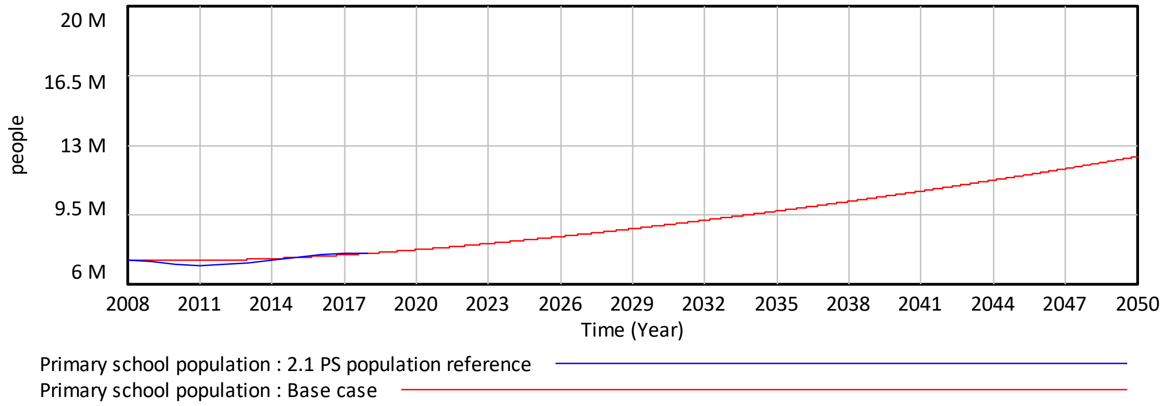

Figure 5.27: Behaviour reproduction test for primary school population stock of education sub-model

Figure 5.28 shows the real-world data[31] of the *secondary school population* in blue and the simulation results in green. The simulation results initially fit the real-world data reasonably well, but deviation from the real-world data increases with time as the real-world data begins to curve downwards.

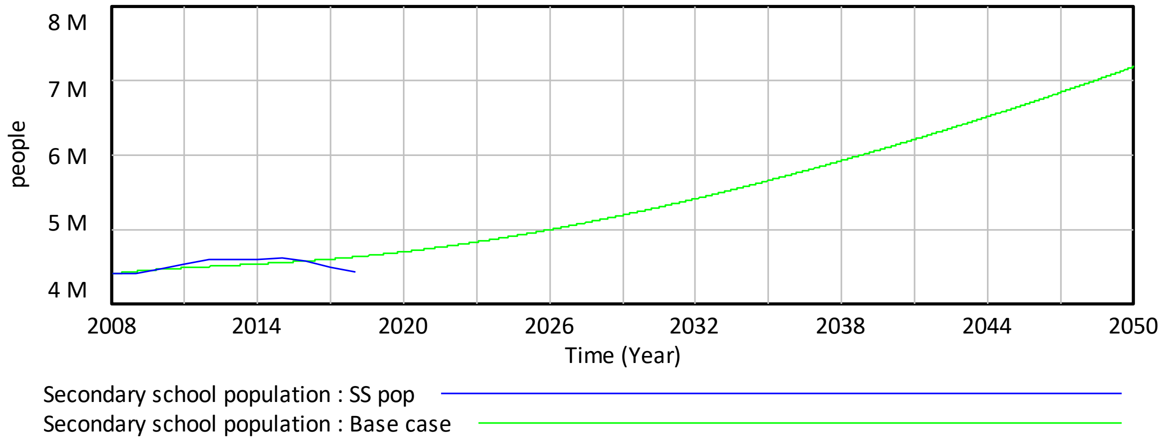

Figure 5.28: Behaviour reproduction test for secondary school population stock of education sub-model

[30] The real-world data for the primary school population was obtained from annual reports, called 'School Realities' , published by the Department for Basic Education in South Africa (2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2019).

[31] The real world data for the secondary school population was also obtained from the reports, called 'School Realities', published annually by the Department for Basic Education in South Africa (2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2019).

Figure 5.29 shows the real-world data[32] of the *undergraduate diploma and bachelor headcount* stock in dark blue and the simulation results in orange. As may be observed from the figure, the simulation results provide a close fit to the real-world data.

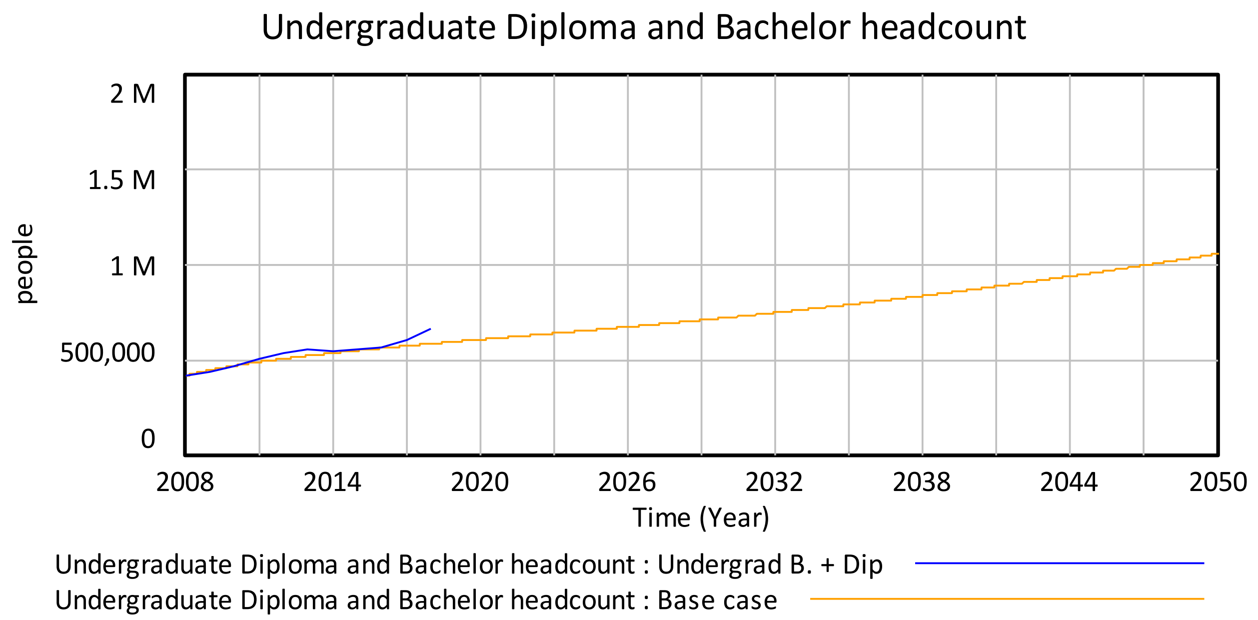

Figure 5.29: Behaviour reproduction test for Undergraduate Diploma and Bachelor headcount stock of education sub-model

Figure 5.30 shows the real-world data[33] of the *LTPC out of school* stock in blue and the simulation results in red. The simulation results start out at the same point as the real-world data and follow a similar downward trend, but with a slope that is less steep.

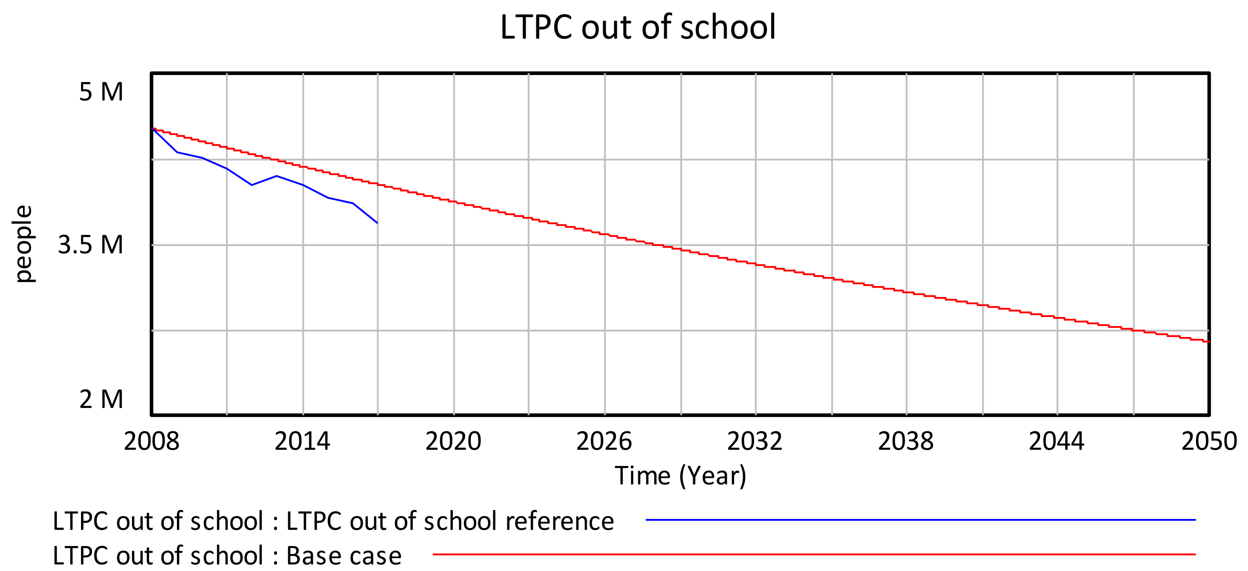

Figure 5.30: Behaviour reproduction test for LTPC out of school stock of education sub-model

[32] The real world data for the undergraduate diploma and bachelor headcount stock was obtained through the Higher Education Data Analyzer (HEDA) developed by IDSC (IDSC, no date).
[33] The real world data for the LTPC out of school stock was obtained from data provided by the Quarterly Labour Force Surveys (QLFS) between 2008 and 2018 (Statistics South Africa, 2008b, 2009, 2018d, 2010, 2011, 2012, 2013f, 2014b, 2015, 2016b, 2017b).

Figure 5.31 shows the real-world data[34] of the *PC out of school* stock in blue and the simulation results in green. The simulation results fit the general trend of the real-world data, but the simulation results do not follow the same pattern of peaks and valleys as the real-world data does.

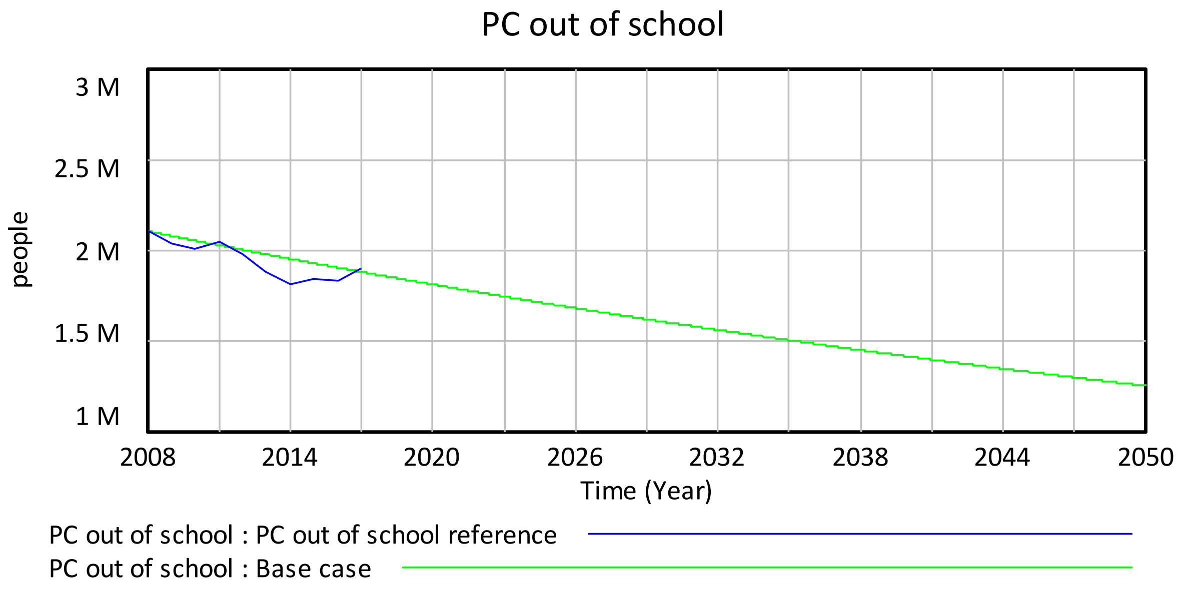

Figure 5.31: Behaviour reproduction test for PC out of school stock of education sub-model

Figure 5.32 shows the real-world data[35] of the *SSNC out of school* stock in dark blue and the simulation results in orange. The real-world data exhibits a general upward trend. The simulation results also follow an upward trend, but with a stope that is less steep and without the same pattern of undulations.

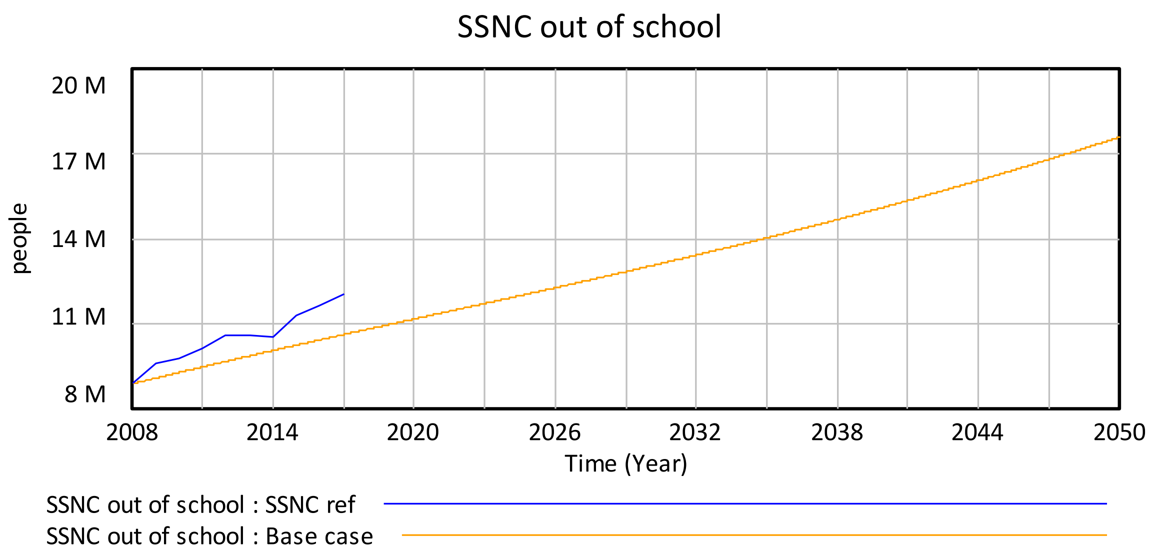

Figure 5.32: Behaviour reproduction test for SSNC out of school stock of education sub-model

[34] The real world data for the PC out of school stock was obtained from data provided by the Quarterly Labour Force Surveys (QLFS) between 2008 and 2018 (Statistics South Africa, 2008b, 2009, 2018d, 2010, 2011, 2012, 2013f, 2014b, 2015, 2016b, 2017b).

[35] The real world data for the SSNC out of school stock was obtained from data provided by the Quarterly Labour Force Surveys (QLFS) between 2008 and 2018 (Statistics South Africa, 2008b, 2009, 2018d, 2010, 2011, 2012, 2013f, 2014b, 2015, 2016b, 2017b).

Figure 5.33 shows the real-world data[36] of the *SSC out of school* stock in blue and the simulation results in red. The real-world data follows a relatively smooth upward trend. The simulation results also follow a smooth upward trend, with a slope that is slightly less steep and without the same pattern of undulations.

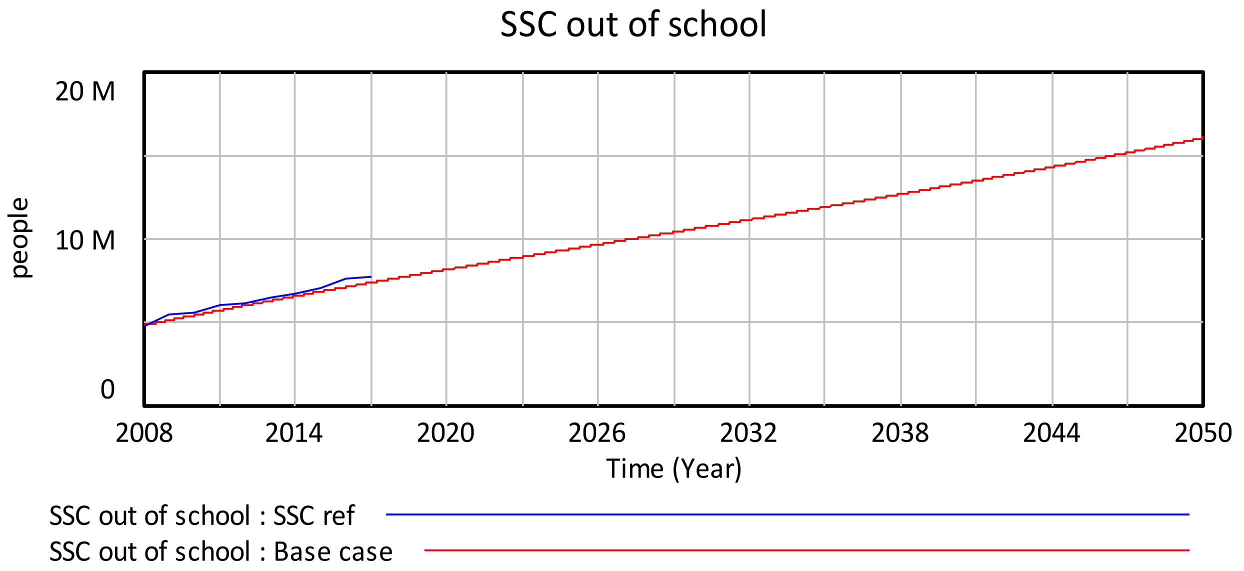

Figure 5.33: Behaviour reproduction test for SSC out of school stock of education sub-model

Figure 5.34 shows the real-world data[37] of the *Tertiary education completed* stock in blue and the simulation results in green. The real-world data initially exhibits a short downward slope, followed by a longer upward slope with a short downward slope at the end, thereby following a general upward trend. The simulation results follow an upward trend with a slope that is less steep than the real-world data and without undulations.

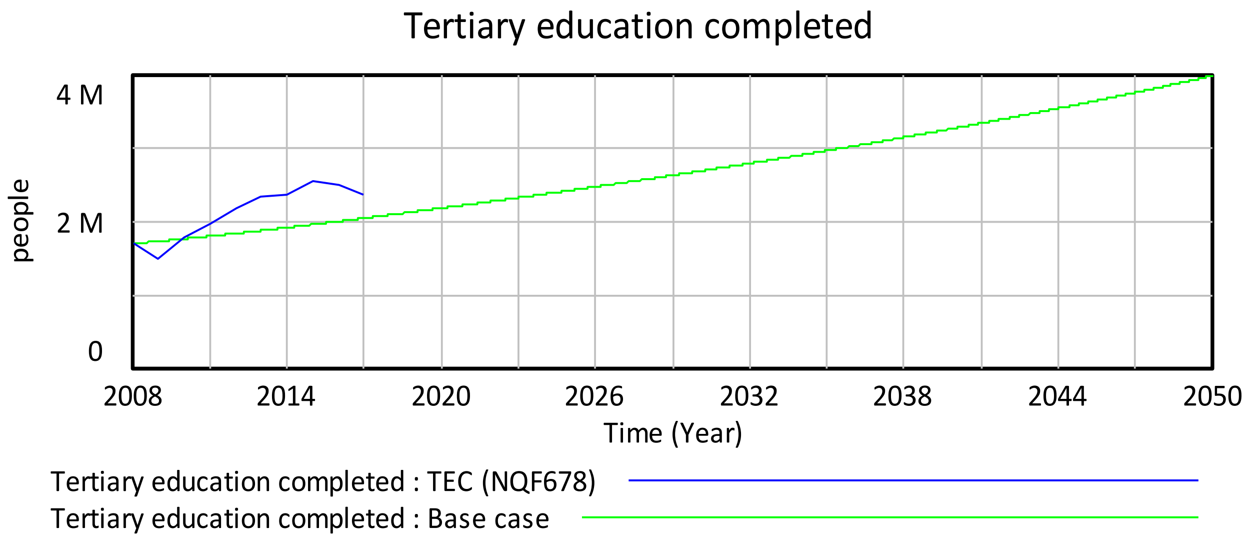

Figure 5.34: Behaviour reproduction test for Tertiary education completed stock of education sub-model

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[36] The real world data for the SSC out of school stock was obtained from data provided by the Quarterly Labour Force Surveys (QLFS) between 2008 and 2018 (Statistics South Africa, 2008b, 2009, 2018d, 2010, 2011, 2012, 2013f, 2014b, 2015, 2016b, 2017b).

[37] The real world data for the Tertiary education completed stock was obtained from data provided by the Quarterly Labour Force Surveys (QLFS) between 2008 and 2018 (Statistics South Africa, 2008b, 2009, 2018d, 2010, 2011, 2012, 2013f, 2014b, 2015, 2016b, 2017b).

5.4.7.2 Income sub-model

Figure 5.35 compares the estimated population trend for the *I1* stock of the income sub-model, in blue, with generated simulation results in red. The figure shows that the reference mode follows a trend with a positive slope and several slight undulations. The simulation results follow a similar slope, however with a trend that lies slightly higher than the reference mode.

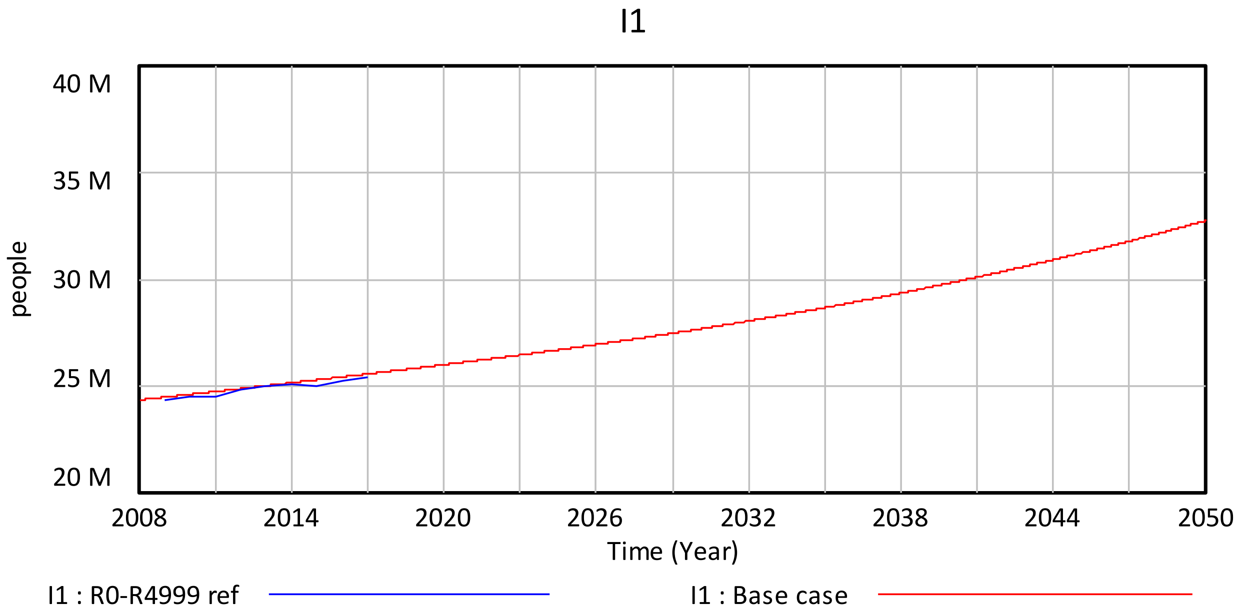

Figure 5.35: Behaviour reproduction test for I1 stock of income sub-model

Figure 5.36 compares the behaviour of the estimated population size of people living in households with an average monthly income of between R5,000 and R9,999 with the behaviour of the simulation results for the *I2* stock. The reference mode, in blue, follows a trend with a positive slope and with several slight undulations. The simulation results, in green, follow a similar trend, but without undulations. These simulation results also generally take on larger values than the reference mode.

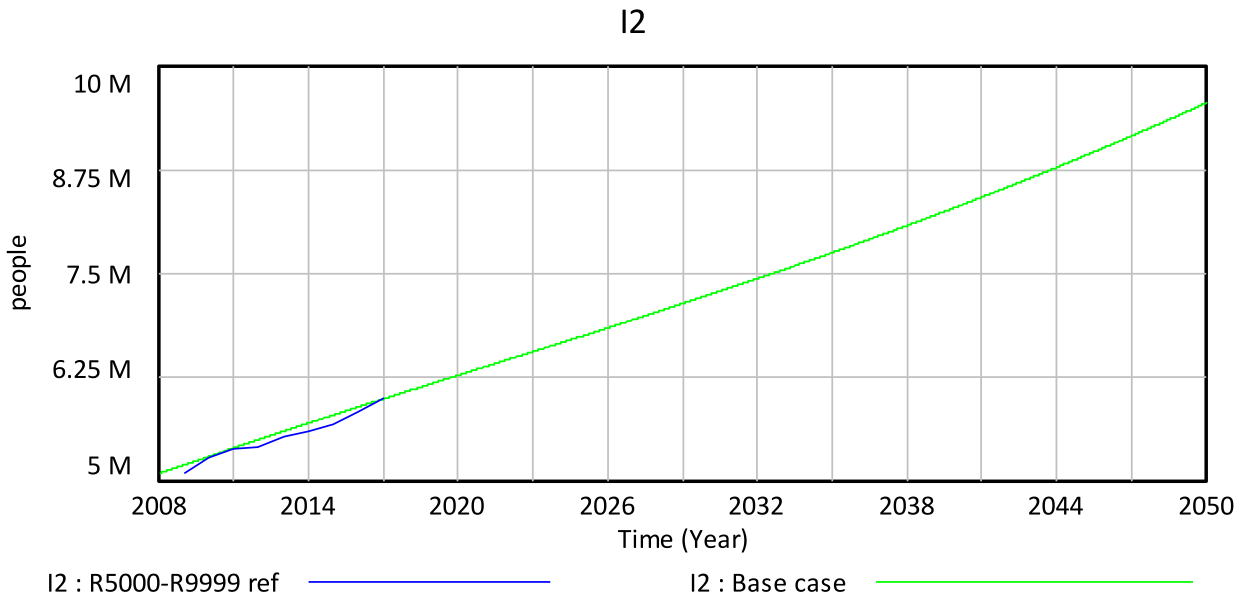

Figure 5.36: Behaviour reproduction test for I2 stock of income sub-model

Figure 5.37 shows how the behaviour of the estimated population of the *I3* stock between 2009 and 2018, in blue, compares to the simulation results in orange. The estimated population for the *I3* stock follows a positive slope with several slight undulations. The simulation results follow a similar trend that is smoother and slightly less steep.

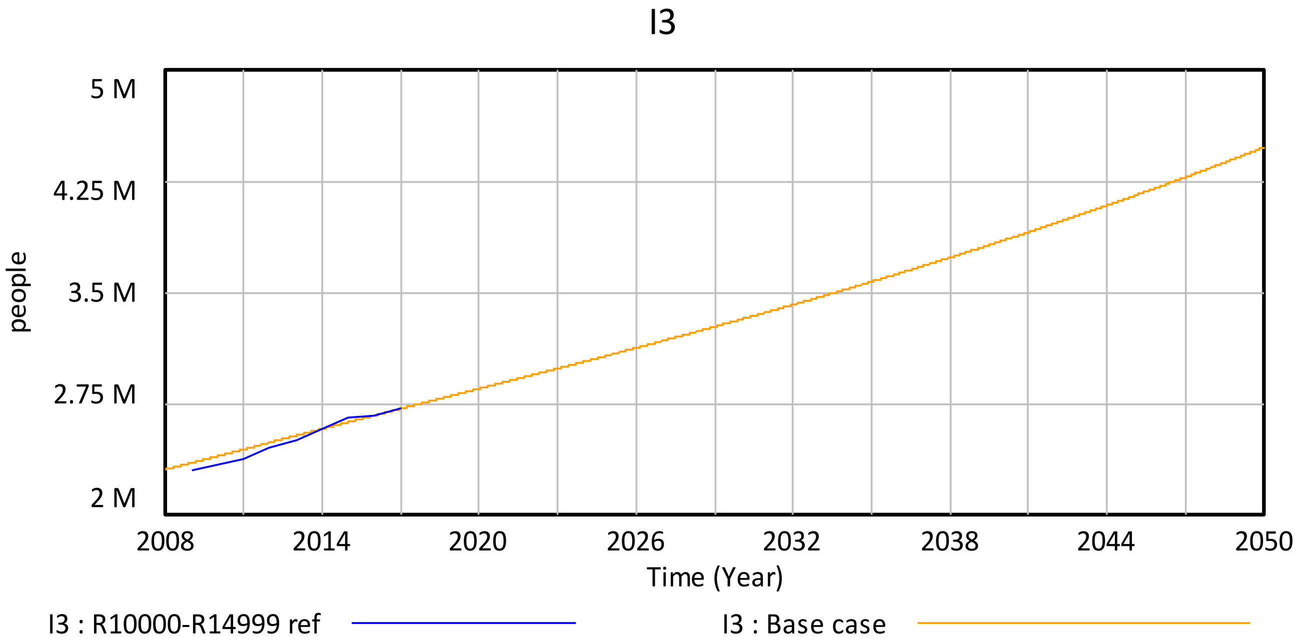

Figure 5.37: Behaviour reproduction test for I3 stock of income sub-model

Figure 5.38 presents the behaviour exhibited by the estimated population size of the *I4* stock between 2009 and 2018, in dark blue, as well as simulation results shown in light blue. The reference mode, in dark blue, generally exhibits a trend with a positive slope and with a few slight undulations. The simulation results follow a similar slope, but a smoother and higher-lying trend.

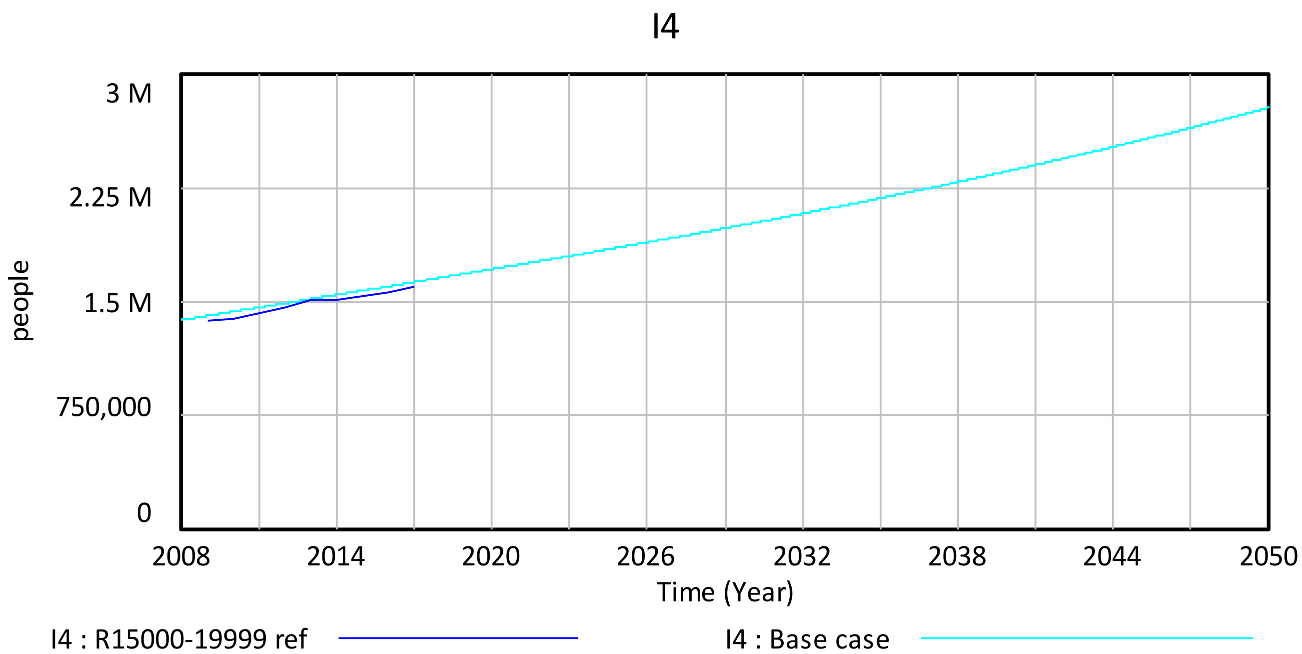

Figure 5.38: Behaviour reproduction test for I4 stock of income sub-model

Figure 5.39 compares the behaviour of the *I5* income category population stock reference mode (blue) with the base case simulation results (pink). The reference mode follows a trend with a positive slope and several slight undulations. The simulation results exhibit a similar slope. However, the trend of the simulation result lies slightly higher and do not exhibit undulations.

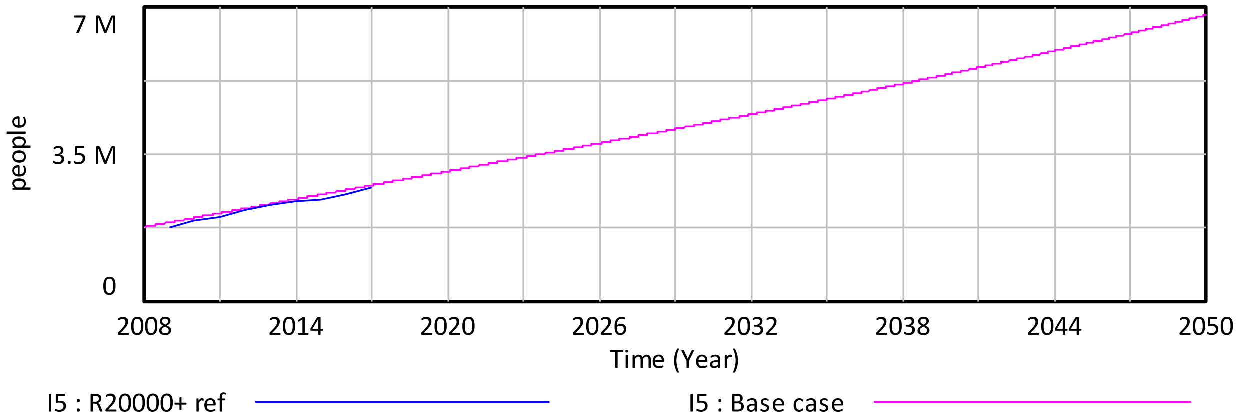

Figure 5.39: Behaviour reproduction test for I5 stock of income sub-model

Figure 5.40 compares the simulation results of the five income category populations under base case conditions. As the simulation results follow the trends of the income category reference modes quite closely, the pattern shown in Figure 5.40 is similar to the pattern of the reference modes shown earlier in Figure 5.3. Figure 5.40 shows that the lowest income category population stock, *I1*, is by far the largest. It may also be observed that each higher income category has a lower population size associated with it throughout the simulation period, with the exception of the highest income category. The faster growth of the *I5* stock is due to the slope of the *I5* stock reference mode which is steeper than the slopes of the other stocks. This steeper slope of the *I5* reference mode may be ascribed to its theoretically infinite income range, which is defined as R20,000 and more. In comparison, the other income categories have a finite range of R5,000. The *I5* stock therefore accounts for several income categories that are above the R20,000 mark. Therefore, the current definition of the *I5* reference mode causes the *I5* stock to grow at a faster rate than the others. The current definition of the *I5* income category as R20,000 and more is due to the limitation of income ranges provided by the 2009-2012 General Household Surveys from which these reference modes have been derived. In these surveys, the highest income value recorded is R20,000. Any higher monthly income is recorded as more than R20,000. This therefore required the definition of a theoretically infinite income range for the *I5* stock.

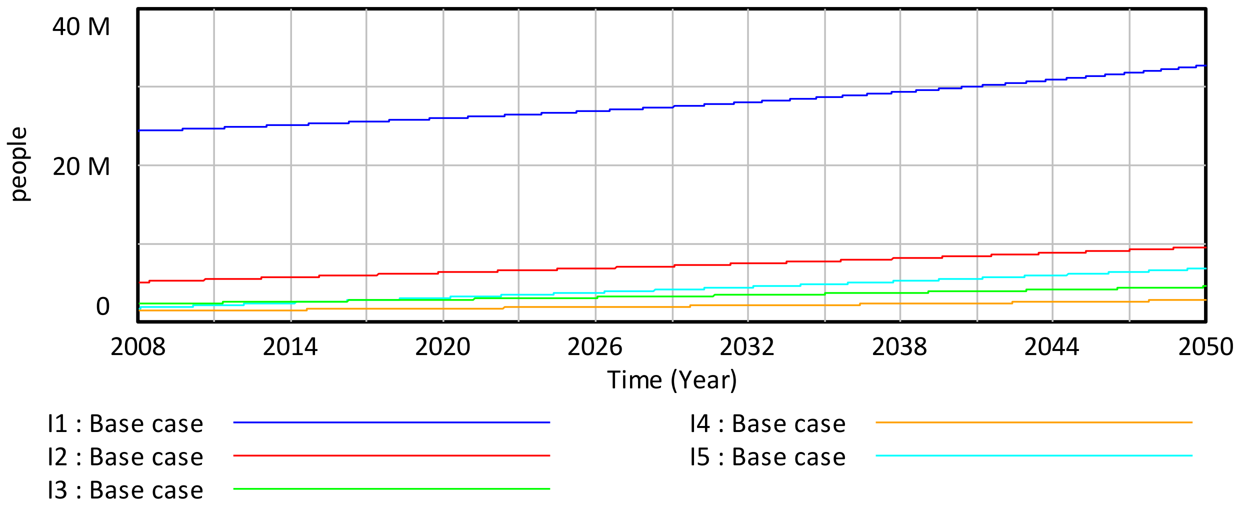

Figure 5.40: Comparison of simulation results for the five income category populations under base case conditions

5.4.7.3 Crime sub-model

No reference modes for the variables of the crime system were available. Therefore, no behaviour reproduction tests could be performed on this sub-model.

5.4.7.4 Behaviour reproduction test conclusion

This sub-section showed that the model was able to reproduce the behaviour of the available reference with varying degrees of accuracy. Considering the purpose at hand, it was concluded that the model reproduced real-world behaviour to a sufficient degree.

5.4.8 Sensitivity analysis

It is important to test the robustness of the conclusions drawn from simulation model against the uncertainty of the assumptions made, because all models are wrong. Sensitivity analysis evaluates whether the conclusions drawn from the model vary significantly with regard to the model purpose, when assumptions are varied over a reasonable range of uncertainty. The two types of sensitivity discussed in this sub-section are numerical sensitivity and behaviour mode sensitivity. Numerical sensitivity occurs when the numerical values of simulation results vary due to a change in assumptions. Behaviour mode sensitivity occurs when the behaviour patterns of the simulation results vary significantly due to a change in assumptions. An example of such a significant behaviour mode variation would be if the behaviour mode of the simulation results change from an s-shaped pattern to an overshoot and collapse pattern, due to a variation of assumptions (Sterman, 2000: p. 883).

Due to the fact that any project is constrained by a certain amount of time and resources, sensitivity analysis should focus on relationships and parameters that are suspected to be both highly uncertain and influential. Parameters around which no uncertainty exists do not need to be tested. If a parameter has no significant effect on the dynamics of the model, it also does not need to be tested, even if its value is highly uncertain. This is because estimation errors for this value have little consequence on the simulation results (Sterman, 2000: pp. 884-885). As mentioned in section 5.1.3, income inequality, inequality of tertiary education access, incidents of robbery, and the culture of crime and violence in South Africa were selected as key output variables for the problem investigated. Therefore, parameters were selected for sensitivity analysis if they significantly influenced the four key output variables and were highly uncertain.

To find such parameters, all highly uncertain constants were evaluated separately with the Monte Carlo simulation function of Vensim DSS. A uniform distribution was defined for these constants with a minimum and maximum value that corresponded to 75% and 125% of the estimated values respectively. 200 simulations were performed where values from the defined distributions were sampled in a random manner. If the output from the Monte Carlo simulation exhibited a significant range of variation on any of the four key variables, the parameter was considered to be both highly uncertain and likely to be influential. Multivariate sensitivity analysis was then performed with these highly uncertain and influential parameters. For the multivariate sensitivity analysis, the Monte Carlo simulation function was applied in the same manner as before, but this time simultaneously with all selected parameters. Table 5.7 shows all the selected parameters, along with the maximum- and minimum values as specified for the multivariate sensitivity analysis.

Table 5.7: Parameters and corresponding values used for multivariate sensitivity analysis

Sub-model	Highly uncertain parameter	Base value	Minimum	Maximum
Education	*SS dropout rate*	0.0844671	0.06335	0.10558
	SSC exit rate	0.741669	0.55625	0.92709
Income	*I1 upward mobility rate*	0.0017258	0.001294350	0.002157250
	I2 downward mobility rate	0.0096093	0.0072070	0.0120116
	I2 upward mobility rate	0.0014278	0.001070880	0.001784800
	I3 upward mobility rate	0.0055254	0.0041440	0.0069067
	I4 downward mobility rate	0.0011492	0.00086	0.00144

	I4 upward mobility rate	0.0027543	0.0020657	0.0034429
	I5 downward mobility rate	0.0012847	0.000963525	0.001605875
Crime	*opportunity to commit robbery*	25000	18750	31250
	criminal and violent culture sustenance factor	0.1	0.075	0.125
	culture fade time	20	15	25

The following four figures present the results for the multivariate sensitivity analysis. The multivariate sensitivity output graphs indicate four confidence bounds, as well as the base case simulation. A 50% confidence bound indicates that 50% of the simulation runs have created results that occurred within the indicated range. Therefore, 25% of the simulation runs have attained a value that is larger than the top of the 50% confidence bound, and 25% of the simulation runs have attained a value that is smaller than the bottom of the 50% confidence bound. As can be seen from the four figures below, the output variables representing access to tertiary education, income inequality, incidents of robbery, and the culture of crime and violence exhibit numerical sensitivity.

Furthermore, from Figure 5.41 and Figure 5.42, it is evident that both the tertiary education completion variable and the income inequality indicator do not exhibit behaviour mode sensitivity under base case conditions. However, from Figure 5.43 and Figure 5.44 it seems that the two key output variables of the crime sub-model do initially exhibit behaviour mode sensitivity when considering the lower bounds of the confidence intervals. The initial behaviour mode sensitivity of these two variables can be clearly observed in Figure 5.45 and Figure 5.46 which display all simulation runs produced during the multivariate sensitivity analysis for each respective variable. From Figure 5.45 it may be seen that the two lowest-lying simulation runs initially follow a decreasing trend and then continue with a behaviour mode that is similar to that of the base case. This therefore indicates slight initial behaviour mode sensitivity of the robbery incidents variable. Figure 5.46 shows that the simulation runs of the criminal and violent culture variable, falling below the base case run, initially follow decreasing trends and then carry on with a behaviour mode that is similar to that of the base case. This therefore also indicates an initial behaviour mode sensitivity of the criminal and violent culture variable.

From the results of the multivariate sensitivity analysis, it was deduced that conclusions gathered from the simulation model vary in an adequate manner when assumptions regarding influential and highly uncertain constants are changed over a reasonable range of uncertainty. This variance should however be kept in mind when interpreting the results generated by the simulation model.

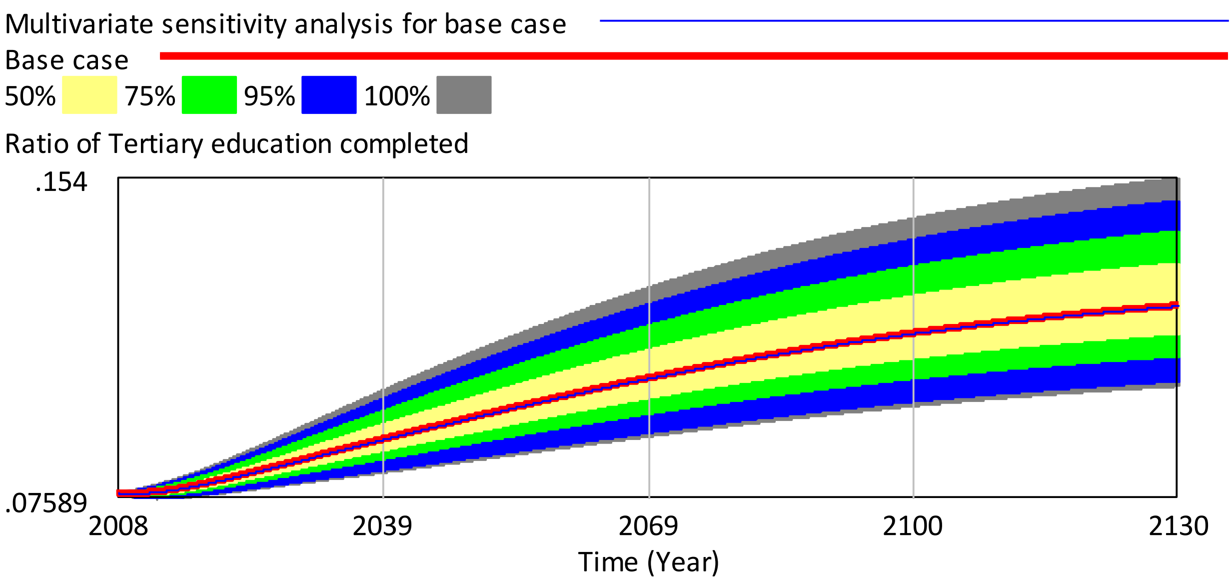

Figure 5.41: Multivariate sensitivity results of the Tertiary Education Completion ratio under base case conditions

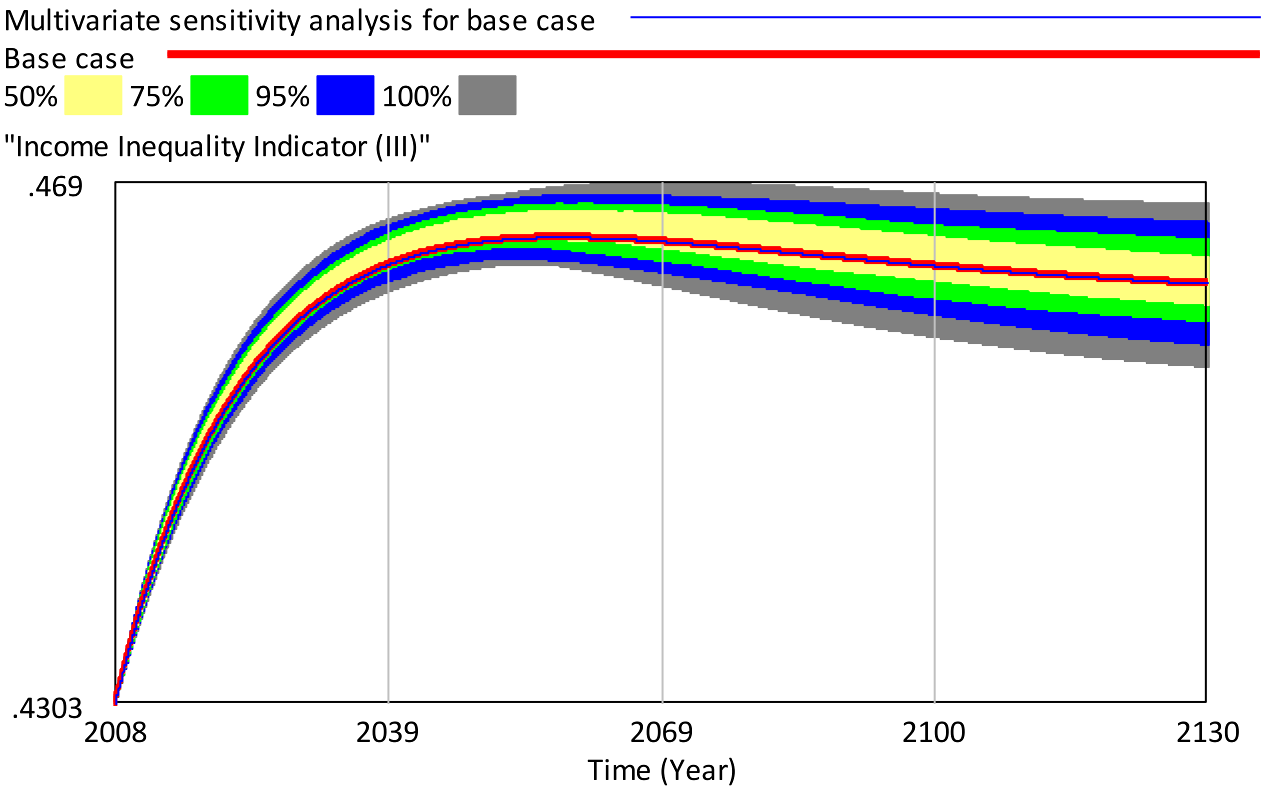

Figure 5.42: Multivariate sensitivity results of the Income Inequality Indicator (III) for base case conditions

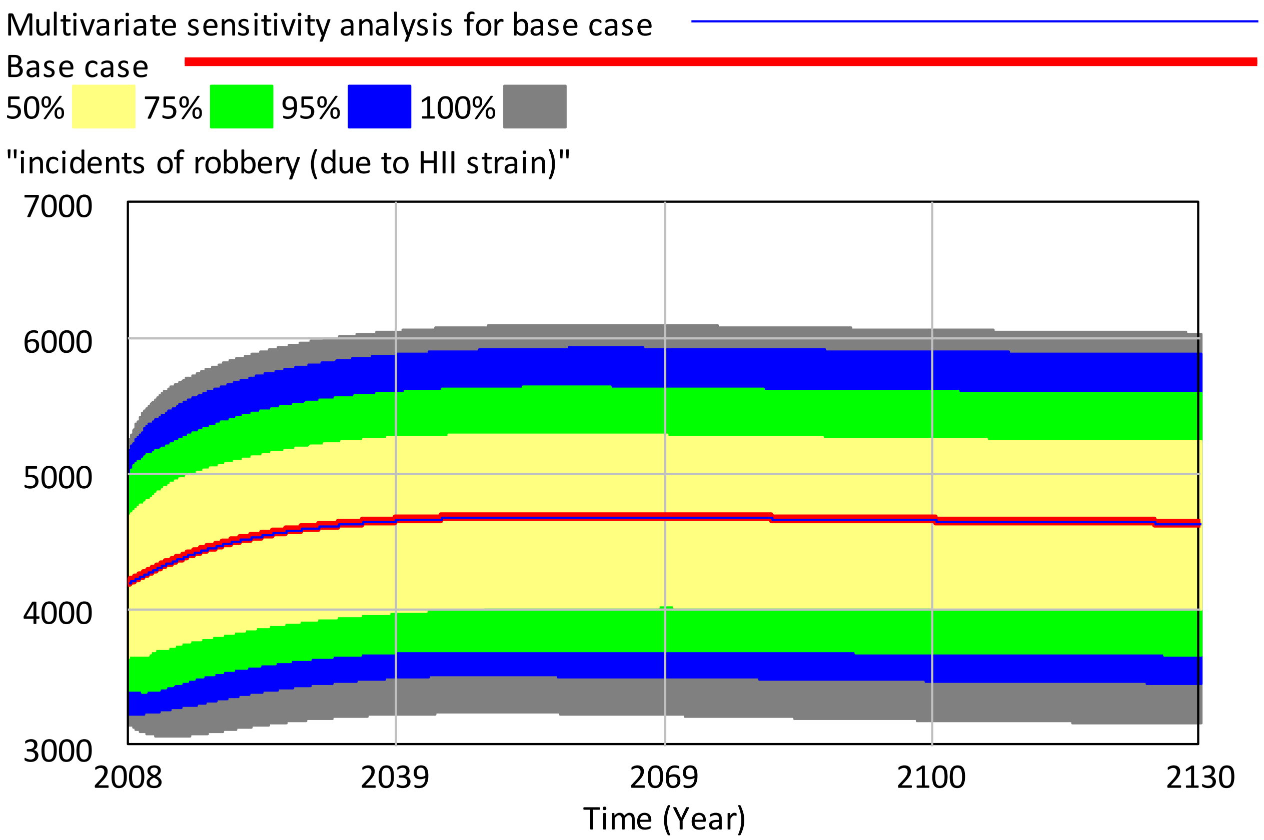

Figure 5.43: Multivariate sensitivity results for incidents of robbery due to household income inequality strain under base case conditions

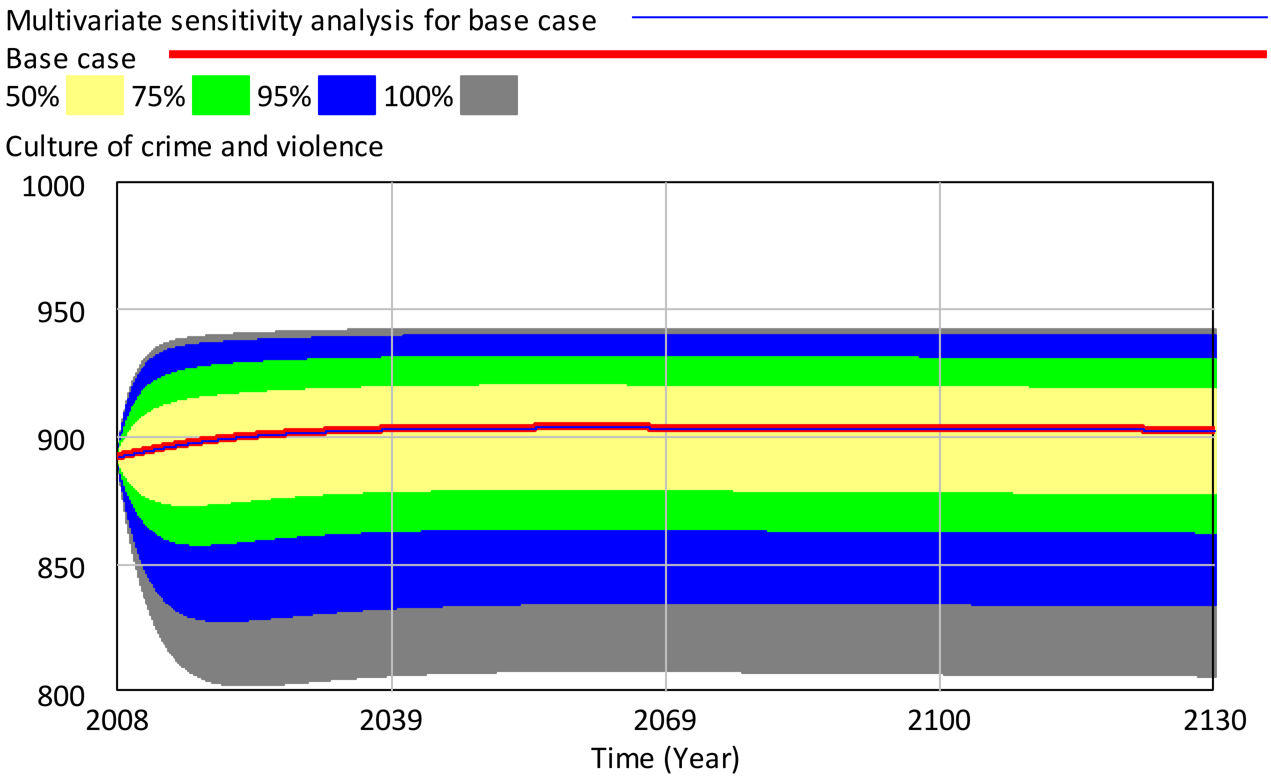

Figure 5.44: Multivariate sensitivity results for the Culture of crime and violence stock under base case conditions

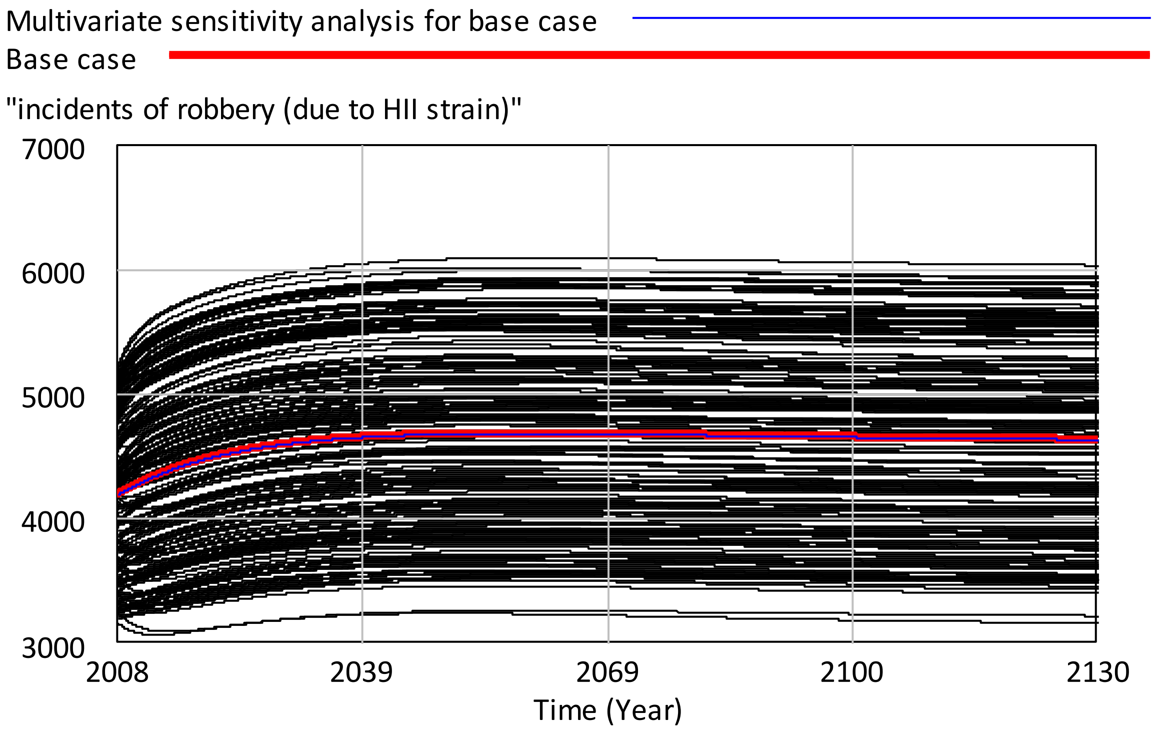

Figure 5.45: Individual simulation runs of the 'incidents of robbery (due to HII strain)' variable produced during multivariate sensitivity analysis under base case conditions

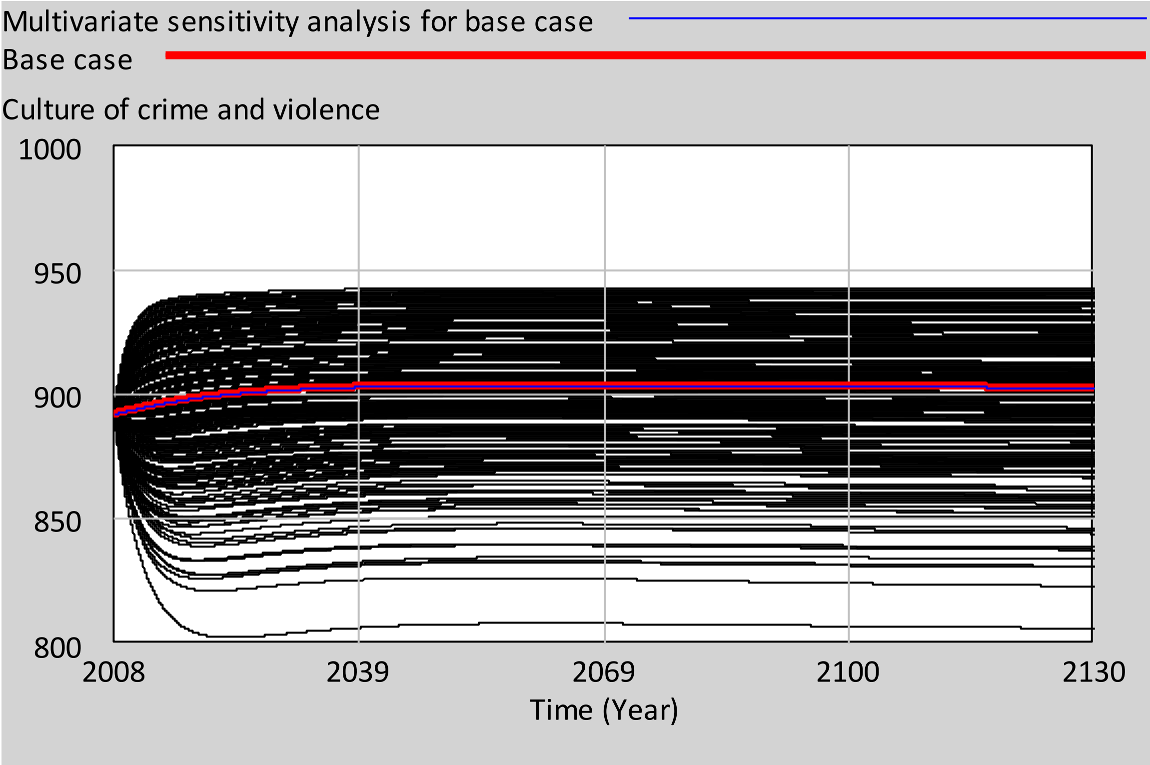

Figure 5.46: Individual simulation runs of the 'Culture of crime and violence' stock produced during multivariate sensitivity analysis under base case conditions

5.5 Chapter conclusions

The beginning of this chapter introduced the purpose of the dynamic hypothesis for this study as an approach to investigate the drivers of robbery at residential- and non-residential premises of South Africa, in the context of a culture of crime and violence that is sustained by income inequality and unequal access to tertiary education. In sections 5.2 and 5.3, this dynamic hypothesis was then presented in the form of a formal simulation model. Lastly, section 5.4 presented various tests applied to the simulation model in order to establish the level of confidence one can have to use the model for its intended purpose. From these tests, various assumptions and simplifications were identified and it was broadly concluded that the simulation model may be considered adequate, but not perfect, regarding the purpose at hand. The next chapter will apply the developed simulation model to generate insight for South African robbery prevention purposes.

CHAPTER 6

Model Results

Contents

All models are wrong, but some are useful. – George Box

The previous chapter discussed the logic and structure of the dynamic hypothesis developed for this study. This chapter presents insights gained from the simulation model regarding interventions of robbery in the context of income- and education inequality. In section 6.1, six robbery prevention interventions are described. These six interventions are used to formulate eleven scenarios which may be applied to the simulation model. Section 6.2 describes the results generated by the eleven scenarios and provides some explanations for these results. In section 6.3, the generated results are used to suggest some policy implications with regards to robbery prevention in South Africa. Lastly, conclusions from this chapter are discussed.

6.1 Scenario experiments

This section defines scenarios for the simulation model that represent various interventions aimed at preventing robbery in the context of South African income inequality and unequal access to tertiary education.

Six points of intervention were identified throughout the development of the model. All interventions have to do with the education system of South Africa. The first intervention represents a 50% reduction in secondary school dropout. As mentioned in sub-section 5.1.4, the South African Schools Act (No. 84 of 1996) stipulates that parents are obliged to ensure that the child attends school only until the child reaches Grade nine or age 15. In their study on South African school dropout, Branson, Hofmeyr and Lam (2014: pp. 109-113) show that both the proportion of pupils repeating and the proportion of pupils not enrolled in school increases significantly from Grade nine onwards. Intervention 1 therefore investigates the effect of a policy that would reduce the number of pupils dropping out of secondary school before completing Grade 12.

The next five interventions are all aimed at increasing access to tertiary education for pupils who have successfully completed Grade 12. The model was constructed in such a manner that tertiary education access rates for Grade 12 pupils from different household income categories may be adjusted independently. The second intervention therefore represents an increase of access to tertiary education for Grade 12 pupils living in households with an average monthly income between R0 and R4,999. The third-, fourth-, fifth- and sixth interventions are similar to the second intervention, but the income categories of Grade 12 pupils differ for each of these interventions. Table 6.1 presents a summary of the six identified interventions.

Table 6.1: Summary of identified intervention points

Inter-vention	Brief description	Constant adjusted	Base case value	Adjusted value
1	A 50% reduction in secondary school dropout rate for learners from all income categories.	*SS dropout rate*	0.0844671	0.04223355
2	Increase access to tertiary education to 50% for matriculants living in households with an average monthly income between R0 and R4,999.	*ia%*	0.0845441	0.5
3	Increase access to tertiary education to 50% for matriculants living in households with an average monthly income between R5,000 and *R* 9,999.	*iia%*	0.156667	0.5
4	Increase access to tertiary education to 50% for matriculants living in households with an average monthly income between R10,000 and R14,999.	*iiia%*	0.301333	0.5
5	Increase access to tertiary education to 50% for matriculants living in households with an average monthly income between R15,000 and R19,999.	*iva%*	0.301333	0.5
6	Increase access to tertiary education to 50% for matriculants living in households with an average monthly income more than R20,000.	*va%*	0.425952	0.5

To test the impact of the previously defined interventions, in isolation and in combination, eleven scenarios were designed. These scenarios are listed in Table 6.2. For Table 6.2, interventions one to six were abbreviated as I1 to I6. Scenarios 1 to 6 represent the six interventions applied in isolation. Scenarios 7 to 11 represent various combinations of the six interventions. Scenario 7 tests the combinational effect of halving the current secondary school dropout and increasing access to tertiary education to 50% for matriculants of the lowest modelled income category. Scenario 8 tests the combinational effect of increasing tertiary education access to 50% for matriculants of the four highest income categories accounted for by the model. Scenario 9 tests the same combination as scenario 8, but with the additional effect of halving the current secondary school dropout rate. Scenario 10 tests the effect of increasing access to tertiary education for matriculants from all income categories. Lastly, scenario 11 tests the effect of implementing all defined interventions simultaneously. The results generated from these scenarios are discussed in the next section.

Table 6.2: Scenarios developed from the six identified interventions

Scenario	I1	I2	I3	I4	I5	I6
1	x					
2		x				
3			x			
4				x		
5					x	
6						x
7	x	x				
8			x	x	x	x
9	x		x	x	x	x
10		x	x	x	x	x
11	x	x	x	x	x	x

6.2 Scenario results

This section presents the results generated by the model for the scenarios defined in the previous section. The model output regarding four key variables is described for each scenario.

6.2.1 Base case

This sub-section presents the results generated by the base case created for the simulation model. The base case represents a situation where no interventions are applied to the model. The base case therefore serves as a benchmark that may be used to evaluate the results generated by the defined scenarios.

Figure 6.1 presents the base case output of a ratio that is computed as the number of people that completed tertiary education[38] over the total number of people that have attained some form of final education level. This ratio therefore serves as a measure of tertiary education completion among members of the South African population that are no longer attending educational institutions. As may be observed in the figure, this measure initially follows a slight declining trend, but soon afterwards starts to follow a logarithmic increasing trend for the rest of the simulation period.

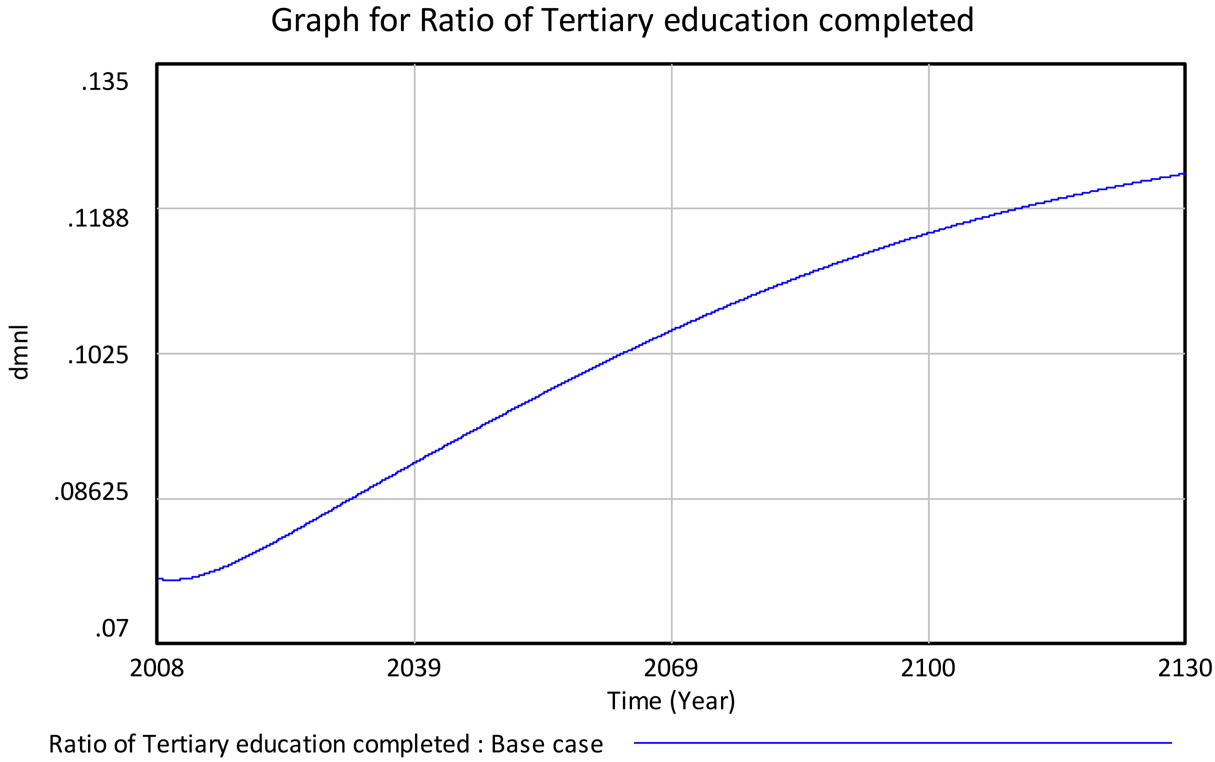

Figure 6.1: Base case output for the tertiary education completion measure

Figure 6.2 presents the behaviour of the *Income Inequality Indicator (III)* under base case conditions. It must be noted that the III generated from this model is significantly lower than the Gini coefficient for South Africa as previously shown in sub-section 4.1.2. This is ascribed to the limited model structure. The model only accounts for five income categories. This is due to the income ranges captured in the responses of the General Household Surveys and Quarterly Labour Force Surveys conducted between 2009 and 2017. If additional income categories for higher incomes were available, the model would show that smaller groups of people earn higher incomes, which would increase income inequality and therefore also the Income Inequality Indicator. The Income Inequality Indicator is computed from this survey data and thus the indicator generated by the model must be interpreted with this in mind.

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[38] As mentioned in the previous chapter, tertiary education for this study only refers to diplomas with Grade 12/Standard 10, bachelor's degrees, post-graduate diplomas and honours degrees.

Figure 6.2 shows that the Income Inequality Indicator (III) exhibits a slight increasing trend between 2008 and 2040. An investigation of the model revealed that this increasing trend is caused by the steep positive trend of the *I5* stock. Figure 6.3 provides a visual comparison of how the *I1* stock grows over two time intervals in comparison to the other income category population stocks. The column graph shows that the *I5* stock triples in size between 2008 and 2040, which is the time period of significant increase for the III. On the other hand, between 2040 and 2070, a time interval of similar size as the previous one, the *I5* stock less than doubles. This therefore shows that the *I5* stock exhibits a significantly lower rate of growth in proportion to its size between 2008 and 2040 than between 2040 and 2070.

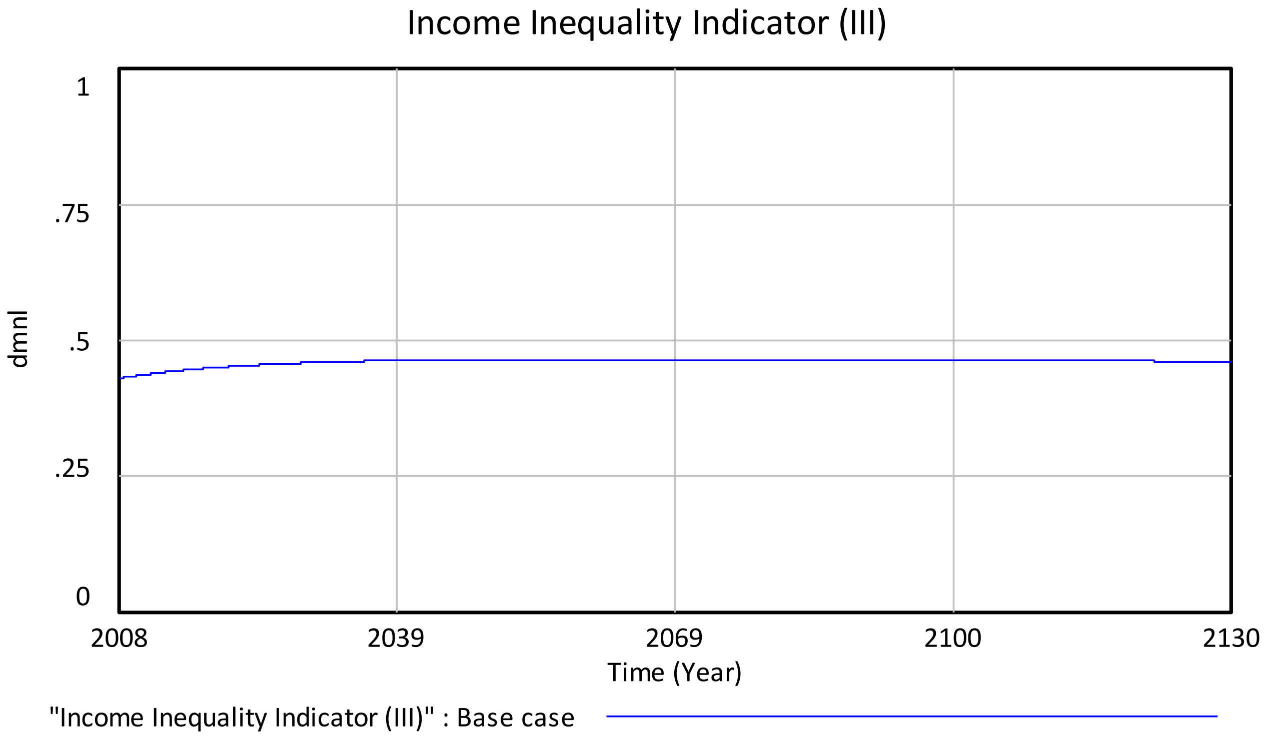

Figure 6.2: Base case output for the Income Inequality Indicator (III)

Table 6.3[39] provides the percentage increase of the five income category population stocks for the two time intervals as shown by Figure 6.3. The table confirms that the *I5* stock more than triples during the first time interval, while the other four stocks, especially *I1*, increase at a significantly lower rate during the same time interval. When taking a close look at Figure 6.2 it may be seen that the Income Inequality Indicator exhibits a slight decreasing trend from 2040 onwards. Table 6.3 reveals that during the second time interval, the four highest income category stocks, especially *I5*, exhibit a lower rate of increase than during the first time interval. The *I1* stock, however, exhibits an increased rate of growth during the second time interval.

The following may therefore be concluded from the behaviour of the model's Income Inequality Indicator (III) during base case conditions. The strong growth rate of income category stocks *I2-I5* between 2008 and 2040 results in a more even population distribution among income categories, which translates into an increase of income inequality as calculated by the III. The decreased proportional growth rate of income category stocks *I2-I5* together with the increased proportional growth rate of the *I1* stock between 2040 and 2070[40] generates a less even population distribution among income categories, which translates into a decrease of income inequality as calculated by the III.

[39] The values in this table have been rounded to the nearest whole percentage.
[40] A similar pattern of rate of change is exhibited from 2070 onwards for the base case.

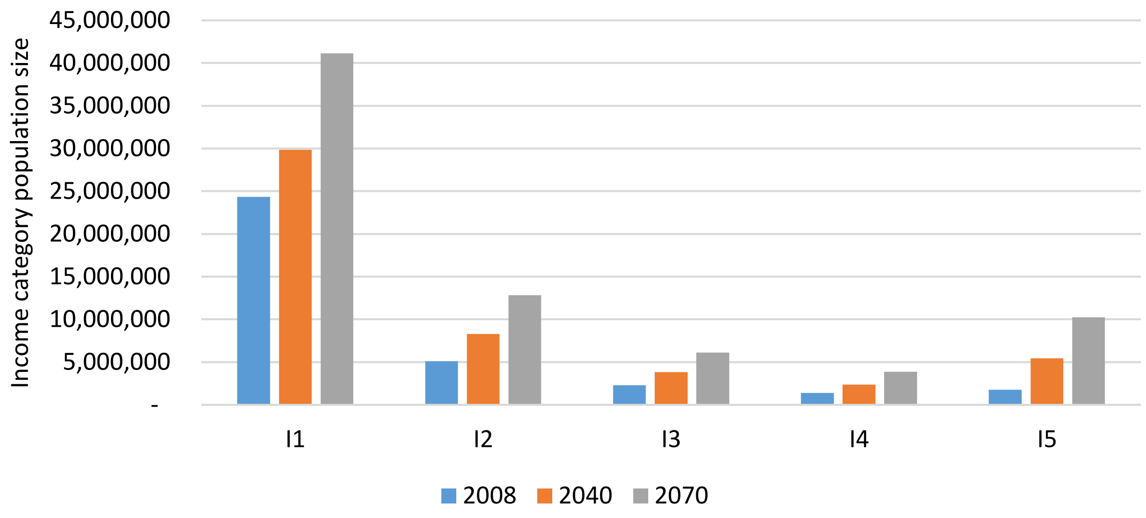

Figure 6.3: Base case output for income category populations I1-I5 in 2008, 2040 and 2070

Table 6.3: Relative percentage increase of the five income category population stocks

	I1	I2	I3	I4	I5
% increase from 2008 until 2040	23%	63%	67%	71%	206%
% increase from 2040 until 2070	38%	54%	59%	64%	89%

Figure 6.4 presents the base case output of the annual number of robbery incidents that occurred due to strain that is caused by income inequality. Note the similarity in behaviour between the Income Inequality Indicator and the number of annual robberies. This similarity shows the strong relationship between income inequality and robbery committed due to income inequality represented in the model.

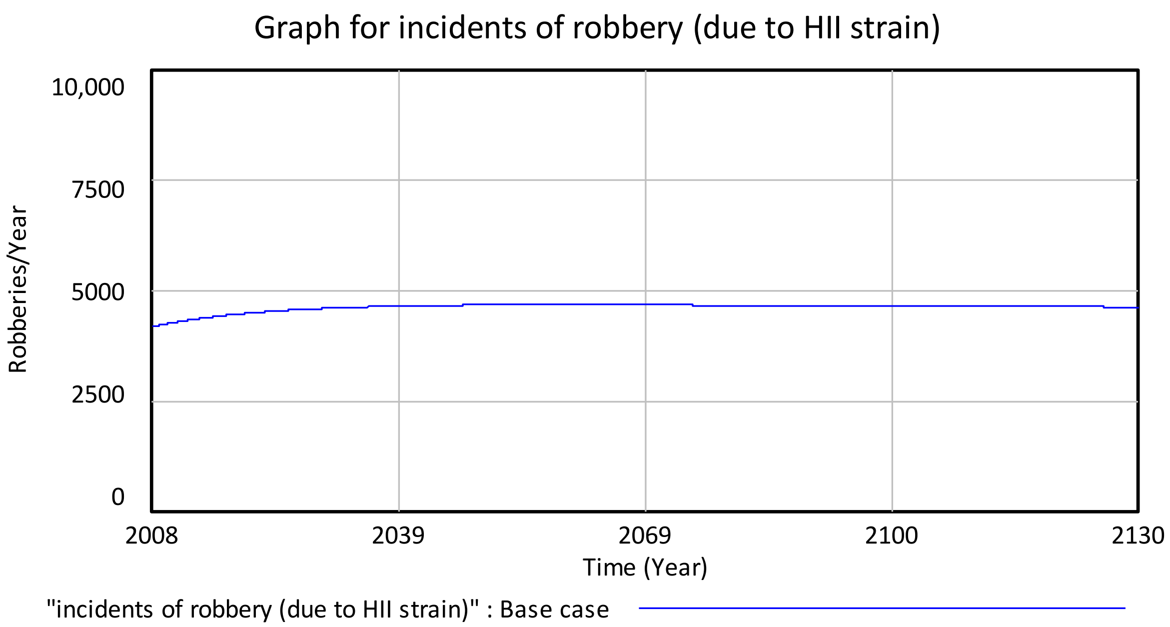

Figure 6.4: Base case output regarding the number of annual robbery incidents that occurred due to strain caused by household income inequality

Figure 6.5 presents the base case output for the variable that represents the level of criminal and violent culture present in South African society. It should be noted that the maximum level of criminal and violent culture possible in the model is 1000 *CV culture* units. Therefore, the simulated criminal and violent culture exists around 90% of the highest attainable value throughout the simulation period under base case conditions. The criminal and violent culture stock variable exhibits an increasing trend between 2008 and 2040, whereafter a declining trend is exhibited until the end of the simulation period. Therefore, this variable exhibits a behaviour pattern that is similar to the number of robberies occurring. This thereby portrays the strong influence, as defined in the model, that robbery incidents have on the level of crime and violence in South African society.

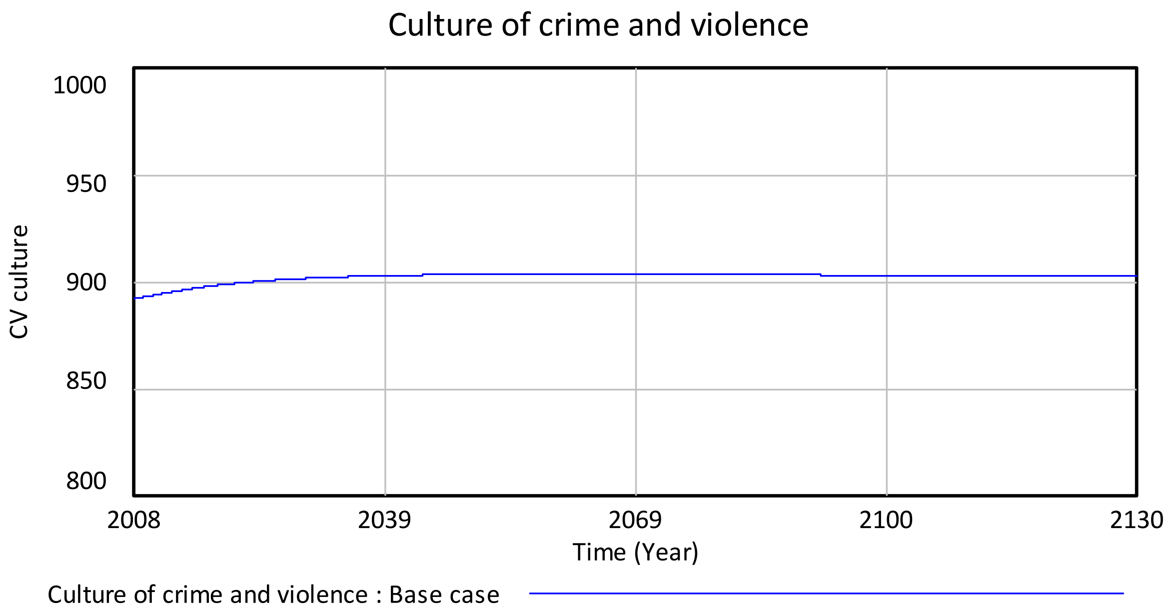

Figure 6.5: Base case output for the level of criminal and violent culture present in South African society

6.2.2 Tertiary education completed

This sub-section briefly compares and discusses the output behaviour generated by the model variable which represents a measure of tertiary education completion among the South African population that is no longer attending any type of educational institution.

Figure 6.6 shows the generated behaviour of the tertiary education completion measure for the base case and the first six scenarios which represent the isolated implementation of the six identified interventions. The graph clearly indicates that scenario 2, where tertiary education access for Grade 12 pupils living in households of the lowest income category is increased to 50%, generates the largest increase in tertiary education completion when considering only isolated implementations of the identified interventions. Scenario 1, a 50% reduction in secondary school dropout rate, generates the second largest increase in tertiary education completion. Scenarios 2 to 5 generate sequentially lower increases in tertiary education completion, while scenario 6 generates an output that is similar, but slightly lower than scenario 4.

As previously shown in Table 6.1 and Table 6.2, scenarios 2 to 6 represent increases in tertiary education access for Grade 12 pupils living in households for which five income categories have been defined. It should be noted that for these scenarios, tertiary education access for pupils from households of different income categories is increased to the same level (50%) although tertiary education access currently differs for each income category. Table 6.1 shows that pupils living in households of the lowest income category currently have the lowest probability of accessing tertiary education (8.45%), while pupils living in households of the highest income category currently have the highest probability of accessing tertiary education (42.60%). This means that the intervention of scenario 2 implies a much larger increase in current tertiary education access than the intervention of scenario 6.

Additionally, the respective sizes of Grade 12 learner populations within each income category should be considered when interpreting the generated results. Table 6.4 shows the respective number of Grade 12 pupils, of the five income categories, in 2008 for the base case scenario. The table shows that, according to the model's generated results, most Grade 12 learners live in households of the lowest income category. Each higher income category consists of less Grade 12 pupils than the previous one, with the exception of the highest income category. The highest income category consists of more Grade 12 learners than the third income category. This is due to limitations of the model structure. The final income category accounts for a much larger income range than the previous four. In reality, each higher income category should consist of less Grade 12 learners than the previous one.

With these definitions of the model structure in mind, one can explain the behaviour presented in Figure 6.6. Scenario 2 generates the highest increase in tertiary education completion because of two reasons. Firstly, this scenario receives the biggest increase in tertiary education access because it is increased to 50% from 8.45%, as shown in Table 6.1. Secondly, the population of Grade 12 learners that receives this major increase is also the largest population among the five income category populations of Grade 12 learners, as shown in Table 6.4.

Scenarios 3 to 5 each generate a sequentially lower tertiary education completion ratio than scenario 2, because scenarios 3 to 5 each receive a sequentially lower increase in tertiary education access as shown in Table 6.1. Additionally, each of these scenarios target a sequentially smaller Grade 12 population size for the base case, as shown in Table 6.4. Scenario 6 is an exception to this pattern, because of the limited model structure. The large income range for learners from households of the largest income category creates a population size that is larger than the previous one, as may be seen in Table 6.4. For this reason, more Grade 12 learners receive access to tertiary education in scenario 6 than in scenario 5, leading to a higher tertiary education completion ratio as may be seen in Figure 6.6.

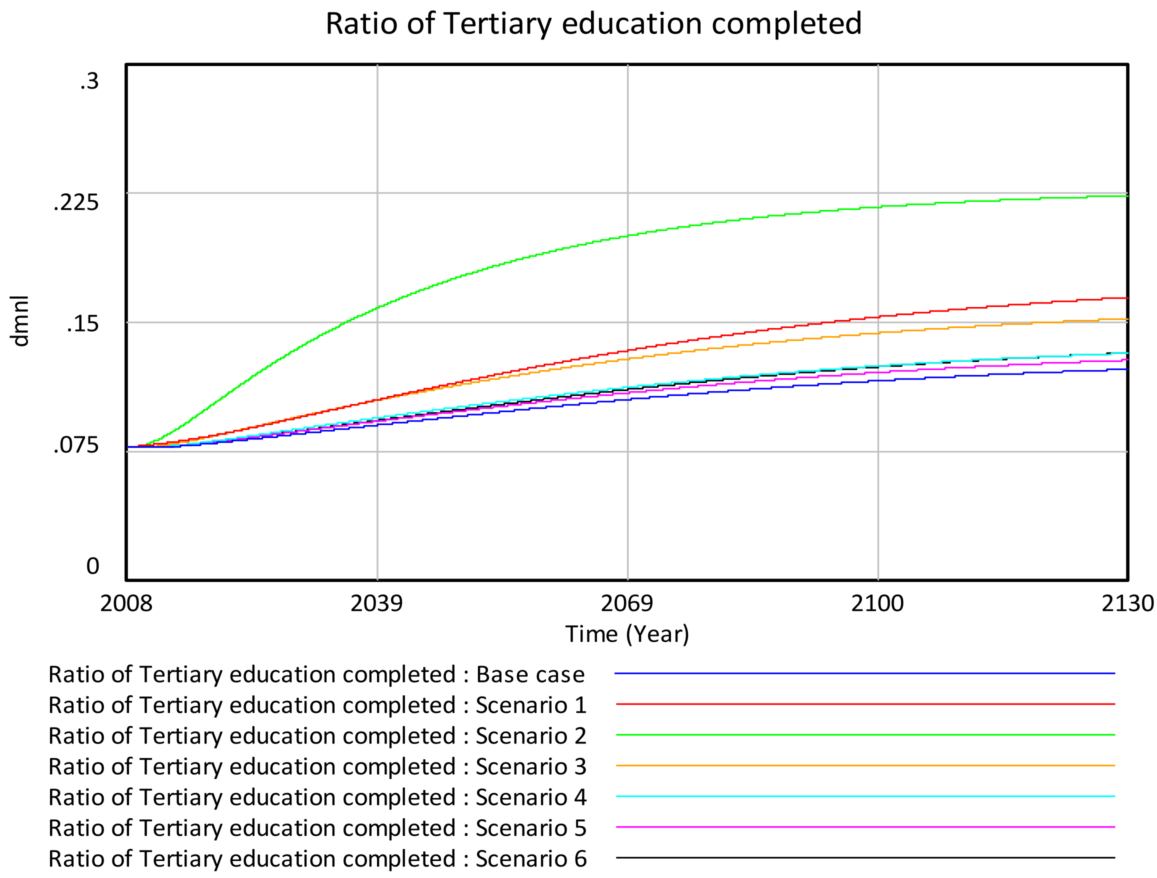

Figure 6.6: Comparison of tertiary education completion ratio generated by the base case and the first six scenarios

Table 6.4: Grade 12 learner distribution among the five income categories calculated by the model under base case conditions in 2008

Average monthly household income range	Number of Grade 12 learners living in households with respective income range
Less than R5,000	401,100
Between R5,000 and R9,999	80,960
Between R10,000 and R14,999	39,950
Between R15,000 and R19,999	21,250
R20,000 and more	47,900

Figure 6.7 shows the tertiary education completion measure generated for scenarios 7 to 11, along with the base case results. These scenarios represent combinations of the six previously discussed interventions. As may be expected, the graph shows that scenario 11, which represents a combination of all defined interventions, generates the highest measure of tertiary education completion.

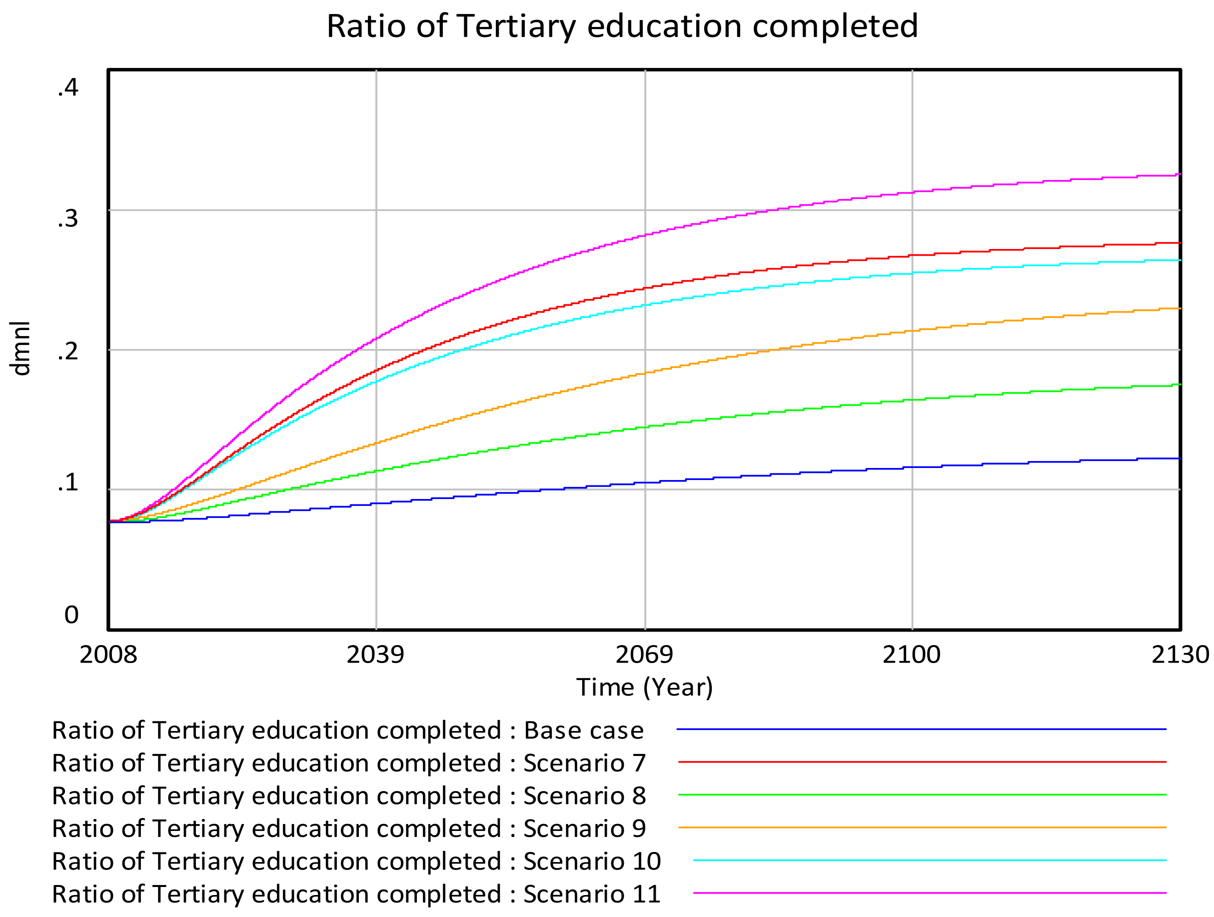

Figure 6.7: Comparison of tertiary education completion ratio generated by the base case and scenarios 7 to 11

Scenario 7, representing a reduction in secondary school dropout rate, as well as an increase in tertiary education access for Grade 12 learners living in households of the lowest income category, generates the second largest combinational effect among the defined scenarios. This scenario is a combination of scenario 1 and 2 discussed earlier, which showed to generate the strongest effects of interventions applied in isolation.

Scenario 10 represents increased access to tertiary education for Grade 12 learners from all income categories. This scenario generates a similar, but lower increase of tertiary education completion than scenario 7. Scenario 9 generates the second lowest increase in tertiary education completion among the combinations of applied interventions. This scenario applies all the interventions applied in scenario 11, the best performing scenario, except for intervention 1. This therefore again shows the strong effect generated by increasing tertiary education access for Grade 12 pupils of the lowest income category. Scenario 8 generates the least, but still considerable, increase in tertiary education completion for interventions tested in combination. This scenario applies all the interventions of scenario 9, except for intervention 1. These results therefore confirm the strong effect generated by halving the current secondary school dropout rate.

The results generated from the eleven scenarios, for tertiary education completion, provide several noteworthy findings. Figure 6.6 showed that scenario 2 by far generated the largest increase in tertiary education completion among interventions tested in isolation. The discussion on this earlier highlighted that this is due to the proportionally large number of Grade 12 pupils in the lowest income category, as well as the currently low tertiary education access rate for these pupils. Scenario 1 generated the second highest increase in tertiary education completion among interventions applied in isolation. This is an indication that halving the current secondary school dropout rate may significantly increase access to tertiary education for Grade 12 pupils. Additionally, when considering interventions in combination, it was found that intervention combinations which included intervention 1 or 2 generated the largest increases in tertiary education completion. This serves as a confirmation that intervention 1 and 2 generate the largest desirable effects for the simulation model regarding tertiary education completion.

6.2.3 Income Inequality Indicator (III)

This sub-section discusses the output generated by the Income Inequality Indicator (III) for each of the eleven scenarios.

Figure 6.8 shows the output generated for the III by scenarios 1 to 6, along with the base case. The graph portrays unexpected behaviour of the III for the six interventions. One would expect that a reduction in secondary school dropout rate and increases in tertiary education access among Grade 12 pupils would immediately generate a lower III (less inequality). The scenarios, however, show that this is not the case. All six scenarios generate an III that is initially higher (more inequality) than the base case and then at some point starts to drop below the base case (less inequality).

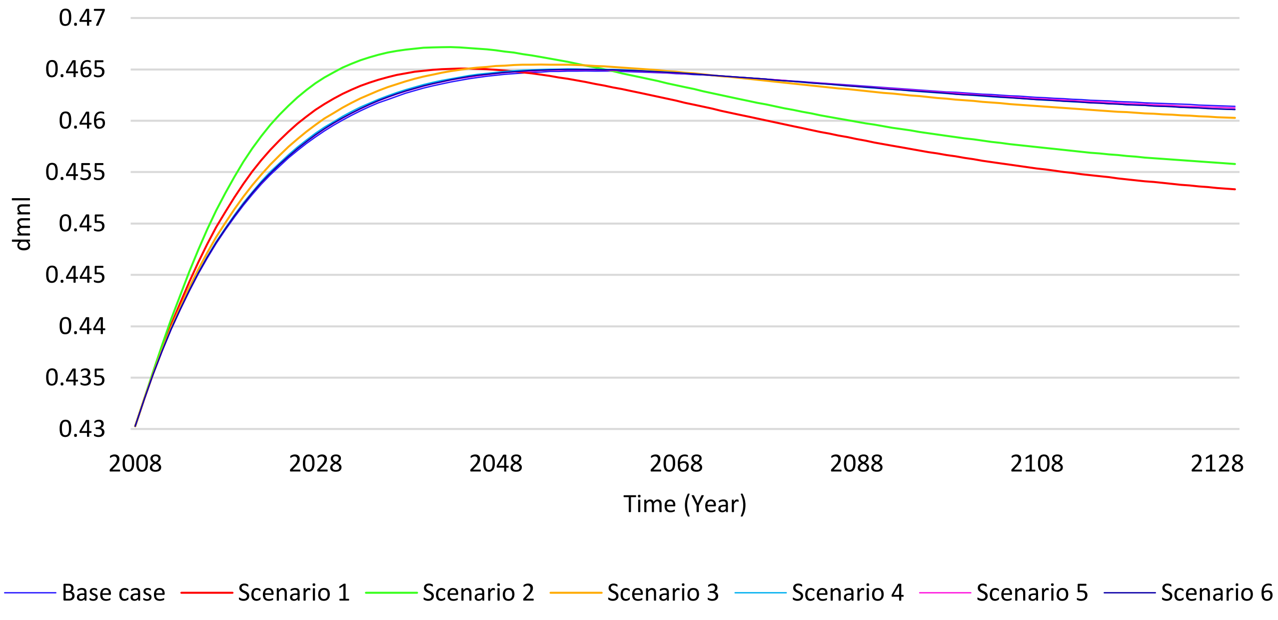

Figure 6.8: Comparison of income inequality measure generated by the base case and the first six scenarios

To explain this behaviour, the earlier discussion in sub-section 6.2.1 on the base case behaviour of the Income Inequality Indicator (III) should be considered. The initial sudden rise of the III during base case conditions is mainly generated by the initial proportionally large increase of population stock *I5*. This generates a more even distribution of people among the income categories and thereby generates a higher III. The proportional rate of growth of this population stock decreases over time as its size increases, until a certain “tipping point” may be observed. At this point the growth rate of the *I1* stock has increased and the growth rate of the *I5* stock has decreased. Further analysis reveals that the proportional growth rate of the *I1* stock keeps increasing and the proportional growth rate of the *I5* stock keeps on decreasing until the end of the simulation period. These changes in growth rates generate population sizes that produce an III which initially increases rapidly, but then gradually decreases after reaching the so-called tipping point.

With this in mind, it may be observed that the scenarios shown in Figure 6.8 reach this tipping point earlier than the base case. This is most clearly seen from scenario 2, in green. Scenario 2 reaches this tipping point at about 2042, whilst the base case reaches this tipping point at about 2056. This earlier arrival of the tipping point may also be observed from the other scenarios.

This earlier arrival of the tipping point may be explained when comparing the proportional growth of the *I1*-*I5* stocks for the base case and scenario 2. Table 6.5[41] shows the difference in growth rates between the base case and scenario 2. From the table it may be seen that between 2008 and 2040, scenario 2 generates a 60% larger growth rate for stock *I5* than the base case. During the same time interval, scenario 2 generates a 5% and 11% greater increase for stocks *I3* and *I4* respectively. However, for the same time interval, scenario 2 generates a 3% lesser increase for both *I1* and *I2*. Table 6.5 also shows that between 2040 and 2070, a lower difference of growth rates is generated between the base case and scenario 2. The same applies to the next two time intervals between 2070 and 2130. Surprisingly, for these last two time intervals, the growth rate difference of the *I5* stock becomes negative. This means that, during this time, the *I5* stock grows faster under base case conditions than under the conditions of scenario 2.

Table 6.5: Percentage difference in growth rates between the base case and scenario 2

	I1	I2	I3	I4	I5
% increase from 2008 until 2040	-3%	-3%	5%	11%	60%
% increase from 2040 until 2070	-2%	-1%	2%	4%	5%
% increase from 2070 until 2100	-1%	0%	0%	1%	-1%
% increase from 2100 until 2130	0%	0%	0%	0%	-1%

To summarise these results, it may be said that scenario 2 initially generates higher growth rates for stocks *I3*-*I5* and lower growth rates for stocks *I1*-*I2*. This difference in growth rates then decreases over time and is even pushed slightly in the opposite direction for *I5* during the last time interval. These initially increased growth rates generated by scenario 2 lead to an initially higher Income Inequality Indicator (III), but also to an earlier tipping point. After reaching the tipping point, the rate of decrease of the III is greater for all of the scenarios than for the base case. This greater rate of decrease, for the scenarios, then eventually leads to an III that is lower than that of the base case.

These results suggest that the current state of South African income inequality will lead to an initial increase in income inequality if the aforementioned interventions are to be applied as discussed. These results occur in the model because the interventions initially generate stronger growth for the three highest income category populations. With this and the model’s limitations in mind, it may be said that an initial increase of income inequality will inevitably be created when attempting to reduce income inequality through a reduction of secondary school dropout and increased access to tertiary education. Therefore, the effects generated by the scenarios should be interpreted in the long run.

[41] The values in this table have been rounded to the nearest whole percentage.

From these results it can be said that the system of inequality has great inertia. This inertia means that changes to the system can only occur over a long period of time. Due to the inherently large number of people living in households of the lowest income category in South Africa, a reduction of income inequality can only occur over an extended time period. Keeping the inertia of the system in mind, it should be noted that once changes have occurred in the system (in other words a reduction of income inequality) these changes will also require a long time to reverse. Therefore, it may be said that the reduction of income inequality brought about by interventions leading to higher levels of education among the South African population will require a long time to generate desirable effects, but these effects will be long-lasting in return. For this reason, these interventions may be considered as effective long-term and long-lasting approaches for income inequality reduction in South Africa.

If the long-term effect generated by these scenarios is taken into consideration, it may be observed that scenario 1 initially produces the second highest increase of the Income Inequality Indicator (III), whilst generating the lowest III at the end of the simulation period. Scenario 2 initially generates the highest increase of the III, whilst producing the second largest III decrease by 2130. Scenario 3, in contrast to scenario 1, initially produces an III that is lower than that of scenario 2, but eventually produces an III that is higher than that of scenario 2. The last three scenarios follow a similar pattern to the pattern formed by scenario 2 and 3: the smaller the initial increase of income inequality, the smaller the final decrease of income inequality. As with the tertiary education completion measure, scenario 1 and 2 generate the strongest desirable effect on the income inequality measure at the end of the simulation period when considering interventions implemented in isolation.

Figure 6.9 shows the Income Inequality Indicator (III) output generated by scenarios 7 to 11, which test the effect of interventions in combination. The graph shows a pattern of results that is similar to that of the tertiary education completion measure discussed earlier. As with the tertiary education completion measure, scenarios 11 and 7 generate the two most desirable results. Although the earlier results showed that scenario 10 produced a larger increase in tertiary education completion than scenario 9, the results portrayed by Figure 6.9 show that scenario 10 generates a higher Income Inequality Indicator than scenario 9. As with the tertiary education completion measure, scenario 8 generates the least desirable effect among the scenarios that test interventions in combination. It should be noted that the three best performing scenarios shown in Figure 6.9 all include a reduction in secondary school dropout, whilst the two least performing scenarios do not. This confirms the strong effect that a reduction of secondary school dropout has on income inequality, as shown earlier in Figure 6.8.

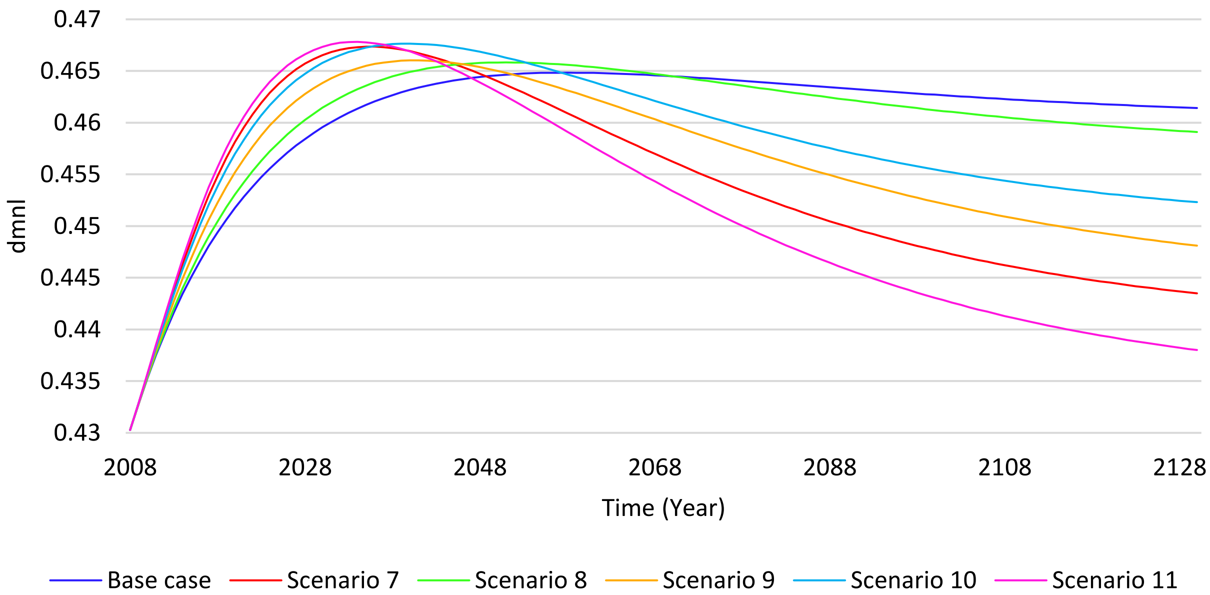

Figure 6.9: Comparison of income inequality measure generated by the base case and scenarios 7 to 11

6.2.4 Incidents of robbery

This sub-section presents the model output generated for the variable that represents incidents of robbery which occur as a consequence of income inequality.

Figure 6.10 shows trends of robbery incidents produced during base case conditions and for the first six scenarios. It should be noted that the patterns of behaviour generated for the robbery variable are very similar to the patterns of behaviour for the Income Inequality Indicator (III). This is due to the model structure which is defined such that the III has a strong influence on the robbery variable. The model structure has been defined in this way to keep within the scope of this study, which focuses on incidents of robbery due to income inequality. For this reason, the behaviour patterns generated by the first six scenarios for the robbery variable, shown in Figure 6.10, are almost identical to the behaviour patterns generated by the first six scenarios for the income inequality measure shown in Figure 6.8. The first two scenarios initially incur the highest increase in robberies, but eventually lead to the lowest number of annual robberies. The last four scenarios produce sequentially lower decreases of robbery at the end of the simulation period, with the exception of scenario 6. Scenario 6 eventually generates a number of robbery incidents that is higher than that of scenario 3, but lower than that of scenario 4.

It should be noted here that the robbery reductions produced by the first six scenarios at the end of the simulation period are small. When comparing scenarios 1 to 6, which apply interventions in isolation, the greatest reduction of robbery is brought about by scenario 1. When comparing scenario 1 with the base case, scenario 1 produces only 114 fewer robberies per year than the base case by 2130. This equates to a 2.464% reduction of annual robberies by 2130.

Furthermore, scenario 5 produces the least reduction in annual robberies among scenarios that apply interventions in isolation. When comparing scenario 5 with the base case, scenario 5 produces only 2 fewer robberies per year than the base case. This equates to a 0.053% reduction of annual robberies by 2130. Scenarios 2, 3, 4 and 6 respectively generate 1.708%, 0.348%, 0.096% and 0.097% reductions of annual robbery by 2130. This indicates that the change brought about by interventions applied in isolation is minimal.

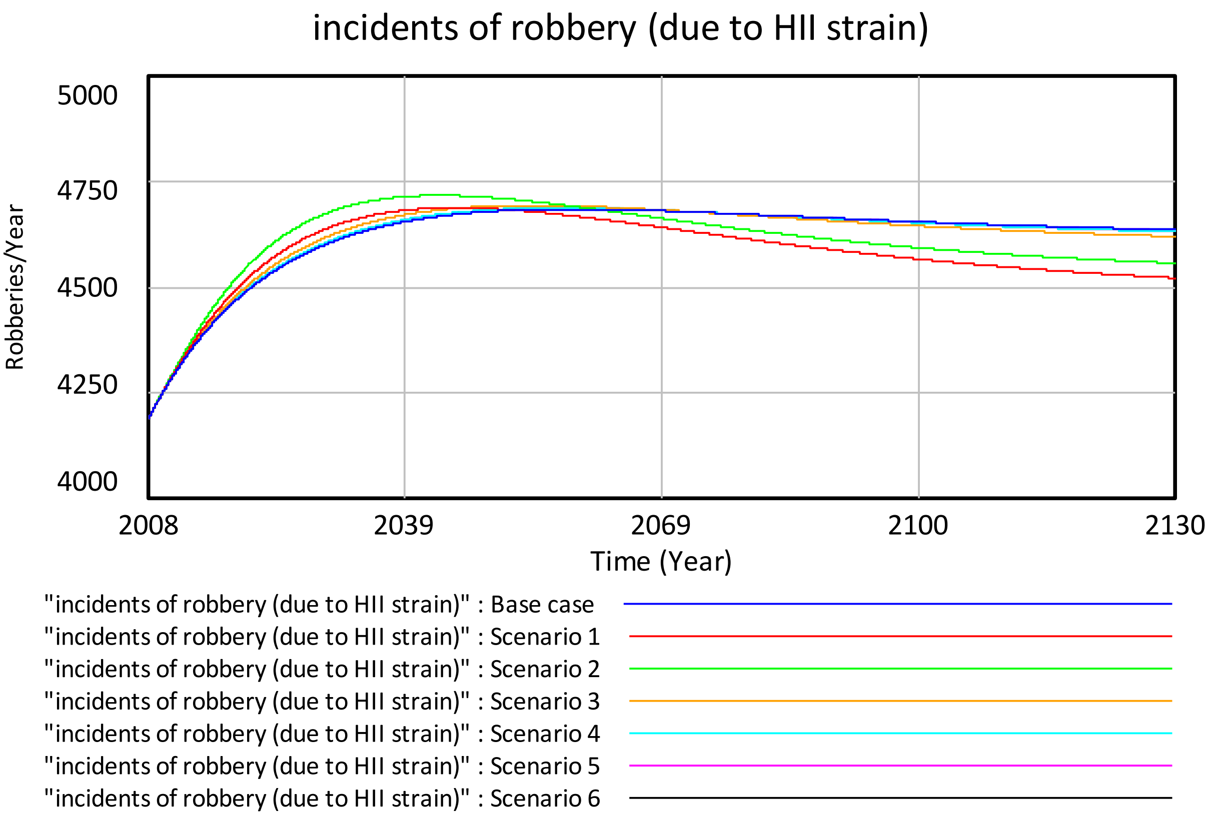

Figure 6.10: Comparison of annual robberies occurring during the base case and the first six scenarios

For scenarios 7 to 11 the behaviour patterns of robbery incidents, shown in Figure 6.11, are likewise similar to the behaviour patterns of the Income Inequality Indicator shown earlier in Figure 6.9. This similarity occurs for the same reason as discussed earlier regarding the behaviour shown by Figure 6.10. Scenarios 11 and 7 initially incur the highest increase of annual robbery incidents, but eventually generate the two lowest numbers of annual robberies. Although scenario 10 initially incurs a number of robberies that is higher than scenario 9, it eventually still generates a higher number robberies than scenario 9. This type of behaviour is only exhibited by scenario 10. Scenario 8 initially produces the least increase in robberies, but also creates the least reduction of annual robberies at the end of the simulation period.

Figure 6.11: Comparison of annual robberies occurring during the base case and during scenarios 7 to 11

6.2.5 Culture of crime and violence

This sub-section presents the results generated for the variable representing the culture of crime and violence in South Africa.

Figure 6.12 displays the output generated by the stock representing the level of crime and violence present in South Africa for the base case and scenarios 1 to 6. For scenarios 1 to 6, the patterns of criminal and violent culture, shown in Figure 6.12, are similar to the patterns of robberies previously shown in Figure 6.10. This shows the strong influence of robbery incidents on the level of criminal and violent culture defined in the model. With regards to the boundary adequacy test in sub-section 5.4.1, it has already been mentioned that the crime sub-model does not account for other factors besides incidents of robbery that influence the level of crime and violence in South Africa. In sub-section 4.1.1 it was seen that various other factors influence the level of crime and violence in South Africa. For this study, however, these factors were not considered, due to the scope of the study. Therefore, the model structure is defined in such a way that the number of robbery incidents are the main influence on the level of criminal and violent culture. For this reason, the behaviour patterns for the level of criminal and violent culture are similar to the behaviour patterns of the robbery variable.

When considering interventions applied in isolation, scenario 1 and 2 eventually generate the two greatest reductions of criminal and violent culture, as shown in Figure 6.12. The last four scenarios generate sequentially lower reductions in levels of criminal and violent culture, with the exception of scenario 6. This scenario generates a reduction in criminal and violent culture that is equivalent to the reduction produced in scenario 4.

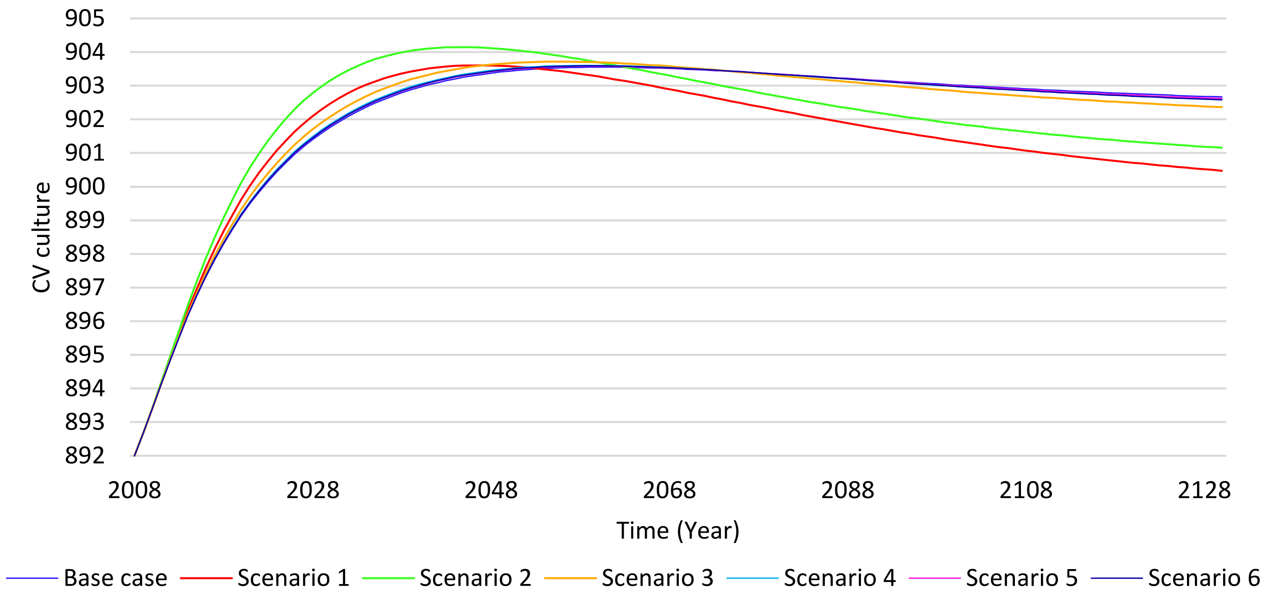

Figure 6.12: Output of stock representing the culture of crime and violence in South Africa for the base case and scenarios 1 to 6

Figure 6.13 displays the trends of criminal and violent culture produced by scenarios that consist of intervention combinations. As for the first six scenarios, scenarios 7 to 11 also produce behaviour patterns that are similar to those of the robbery parameter. For scenarios 7 to 11, with the exception of scenario 10, the criminal and violent culture parameter behaves according to a similar pattern: the higher the initial increase, the lower the eventual decrease. The results for scenario 10 do not follow this pattern. Although scenario 10 initially generates an increase in criminal and violent culture that is comparable with that of scenario 11, it eventually produces a criminal and violent culture level that is higher than that of scenario 9.

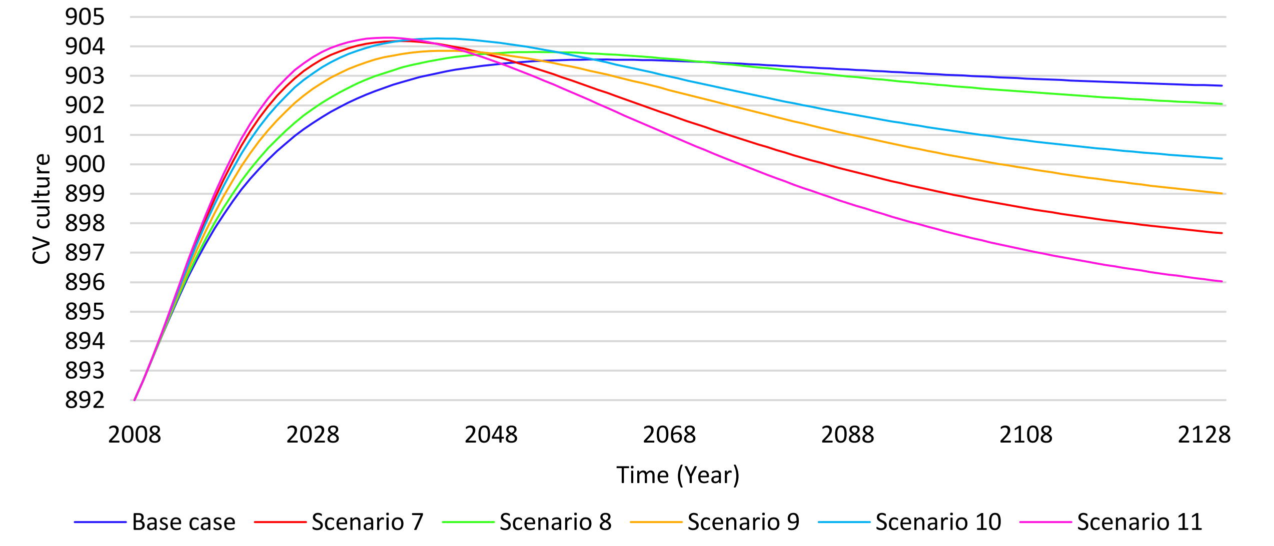

Figure 6.13: Output of stock representing the culture of crime and violence in South Africa for the base case and scenarios 7 to 11

It should be noted that the scale used for Figure 6.12 and Figure 6.13 may let the change produced by the scenarios seem bigger than they are. In all the scenarios the level of criminal and violent culture ranges between 892 and 905 culture units[42]. The permissible range for this variable is between 0 and 1000, with 0 being the minimum and 1000 the maximum. This means that the parameter representing the level of criminal and violent culture does not vary significantly during the scenario runs. This aligns with the discussion in sub-section 4.1.1, where it is argued that various other factors influence the level of criminal and violent culture in South Africa. The simulation results may therefore suggest that the number of robbery incidents do not influence this culture significantly.

6.2.6 Summary of results

This sub-section presents a summary of the results generated by all the described scenarios. Table 6.6 shows the values generated at 2130 by each of the four key output parameters for each of the eleven scenarios, along with the percentage change from the base case value at 2130. The results generally indicate that the more the tertiary education completion ratio increases, the more the number of annual robberies decreases.

When only the results of the first six scenarios are considered, it can be observed that although scenario 1 generates a lesser increase (34.071%) in tertiary education completion than scenario 2 (82.210%), it generates a larger decrease in robbery incidents by 2130. This may be more clearly seen in Figure 6.14. The figure[43] shows, for the first six scenarios, the number of percentage points that robbery decreases for each percent that tertiary education completion increases. For the sake of brevity, this relationship may be referred to as the Robbery over Tertiary Education Completion Ratio (RTECR). Figure 6.14 clearly shows that the RTECR for scenario 1 is the strongest by far. The RTECR decreases progressively between scenarios 2 and 5, and slightly increases again for scenario 6. This pattern may be explained when considering a similar ratio shown in Figure 6.15.

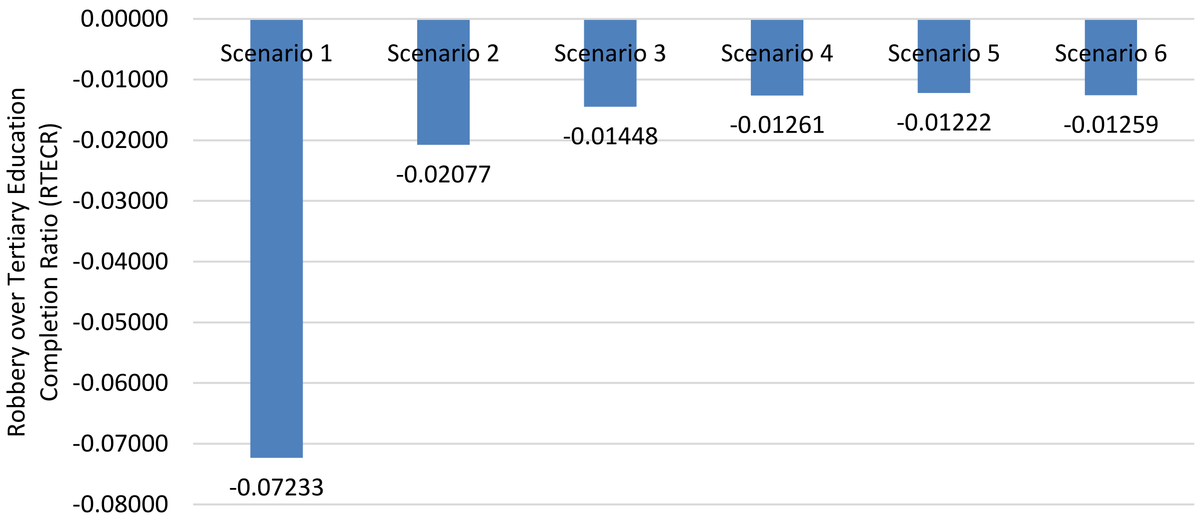

Figure 6.14: Comparison of the Robbery over Tertiary Education Completion Ratio (RTECR) for scenarios 1 to 6 (calculated from values generated at 2130)

Figure 6.15[44] shows the number of percentage points that the Income Inequality Indicator (III) decreases for each percent that tertiary education completion increases in the first six scenarios. This relationship is represented by a ratio that may be called the Income Inequality Indicator over Tertiary Education Completion Ratio (IIITECR). The behaviour pattern of the IIITECR is similar to the behaviour of the previous ratio. This reveals that the unexpectedly strong reduction of robbery in

[42] For the simulation model, criminal and violent culture is measured in units of “CV culture”.
[43] The ratios shown in Figure 6.14 have been calculated from the “Robberies/Year in 2130” column and the “Ratio of tertiary education completed in 2130” column as displayed in Table 6.6.
[44] The ratios shown in Figure 6.15 have been calculated from the “Income Inequality Indicator (III) in 2130” column and the “Ratio of tertiary education completed in 2130” column as displayed in Table 6.6

scenario 1 is due to a strong reduction of the Income Inequality Indicator. This means that the reduction of secondary school dropout implemented by scenario 1 generates a lesser increase of tertiary education completion than scenario 2, but it generates a larger reduction of the Income Inequality Indicator and therefore also a larger reduction of robberies than scenario 2, as may be seen in Table 6.6**.**

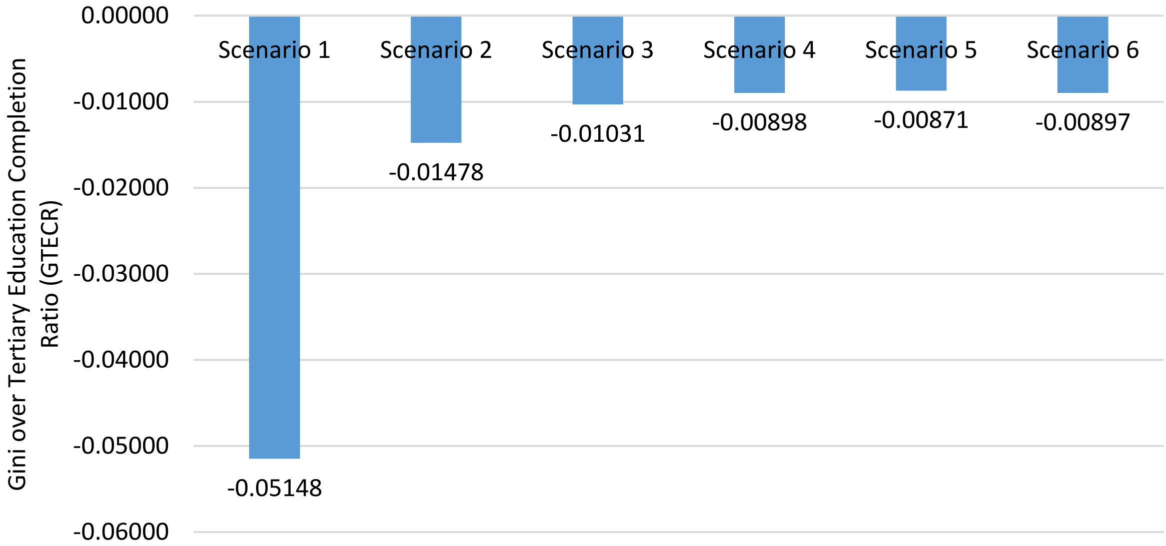

Figure 6.15: Comparison of the IIITECR for the first six scenarios (calculated from values generated at 2130)

Regarding the robbery reduction interventions tested in isolation by scenarios 1 to 6, the following may be concluded. The results show that the more the Income Inequality Indicator (III) is reduced, the more the annual number of robberies is reduced. Scenarios 1 to 5 generate progressively lower reductions of the III and therefore also lower reductions of annual robberies. Scenario 6 generates a slightly larger reduction (-0.069%) of the III than scenario 4 (-0.068%) and therefore also a larger reduction of annual robberies. Additional findings may be gleaned from the results generated by scenarios 7 to 11 that test combinations of the previous six interventions.

The results for scenario 7 show that a combination of interventions 1 and 2 reduce annual robbery incidents by 5.457% and therefore, out of all the scenarios, it forms the second largest reduction of robbery incidents. This could have been expected, as these two interventions generate the largest reductions of robbery when tested in isolation.

A combination of interventions 3 to 6, as implemented in scenario 8, reduces the annual number of robberies by only 0.705% and therefore generates a weak reduction of robbery when compared to the other scenarios. It may be noted here that a combination of interventions 3 to 6, as applied in scenario 8, generates a reduction in robbery that is far less than the reductions produced by either intervention 1 or 2 alone. This also may have been expected, as interventions 3 to 6 applied in isolation generate reductions of robbery that are far less than the reductions produced by intervention 1 or 2.

With a 4.053% reduction, scenario 9 generates the third largest reduction of robbery incidents among the scenarios. It should be noted that this scenario implements the same combination of interventions as scenario 8, which performed poorly, but with the addition of intervention 1. This again highlights the projected strong effect of reducing the current dropout rate in South African secondary schools.

With the implementation of the last five interventions, scenario 10 only generates a 2.771% reduction of annual robberies. This reduction is comparable with the 2.464% reduction that is generated by intervention 1 alone. This suggests that a 50% reduction of the current secondary school dropout rate may generate a reduction of annual robbery incidents that is comparable to the robbery reduction achieved by increasing access to tertiary education to 50% for South African matriculants from all income categories.

A combination formed by all the scenarios, as applied in scenario 11, generates a 7.128% reduction in robbery by 2130, which is the greatest reduction of robberies generated among all scenarios. Therefore, this scenario suggests that a 50% reduction of the current secondary school dropout rate in combination with a 50% tertiary education access rate for matriculants from all income categories may only generate a 7.128% reduction of annual robbery incidents by 2130. This may seem like a marginal effect over the considered time horizon. The benefits of the long-term effects of these interventions, as discussed in sub-section 6.2.3, should be kept in mind though when interpreting these results. As the system seems to exhibit large inertia, the changes brought about through these interventions would remain within the system for a long time. It should also be remembered that only certain qualifications were considered for defining tertiary education. A larger model boundary, incorporating more qualifications[45], may produce stronger robbery-reducing effects.

Another finding, produced by the results of scenarios that implement combinations of interventions, is the concept of synergy. The term 'synergy' stems from the Greek word *synergos*. This Greek word denotes 'working together'. In business, this refers to two or more entities or corporations working together to generate greater value than they could working apart (Goold & Campbell, 1998: p.133). A closer look at the results shown in Table 6.6, reveals that robbery reduction produced by combinations of interventions is larger than the sum of their individual reductions. Figure 6.16 shows the percentage increase of robbery reduction that combinations of interventions generate when compared to the sum of their individual reductions. From the graph it can be observed that scenarios 7, 9 and 11 generate the highest robbery reduction increases due to synergy. It should be noted that only these three scenarios consist of combinations that include intervention 1. This may therefore serve as an indication that the reduction of secondary school dropout is an important intervention to consider when aiming to reduce income inequality, as well as incidents of robbery, due to its synergistic effect. Additionally, the observed concept of synergy suggests that synergy may also occur with combinations of robbery prevention strategies that are currently outside the model boundary. This therefore indicates that a collaborative approach for robbery prevention may exhibit synergy and yield significant results.

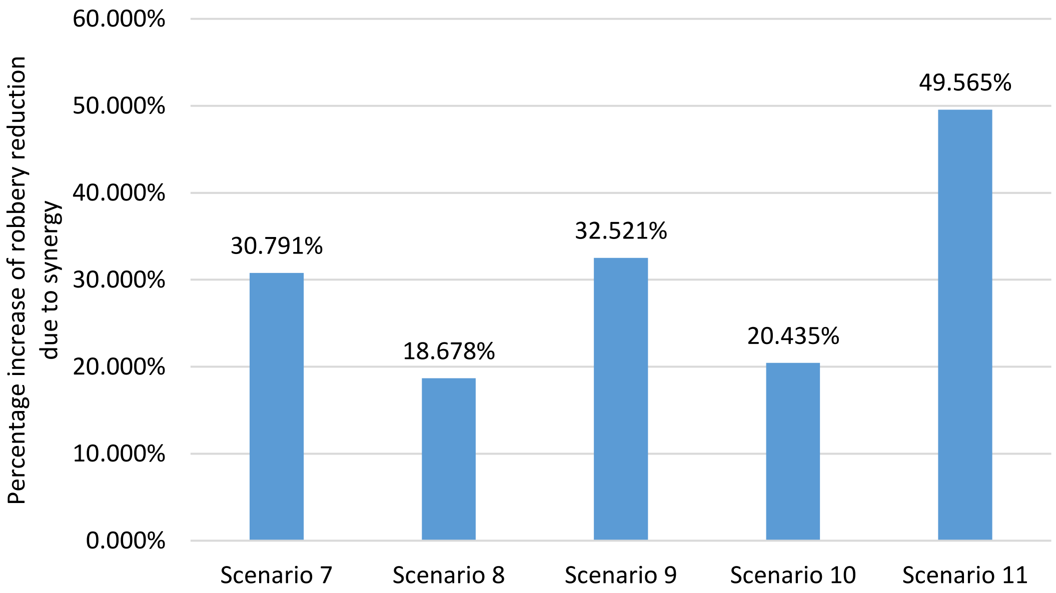

Figure 6.16: Percentage increase of robbery reduction due to synergy exhibited by scenarios 7 to 11

[45] Other qualifications defined by the South African National Qualifications Framework include certificates from Adult Basic Education and Training (ABET) centres, certificates from Technical and Vocational Education and Training (TVET) colleges, as well as masters and doctoral degrees from public and private universities.

Table 6.6: Summary of results generated from scenarios

Scenario	Intervention	Ratio of tertiary education completed in 2130	% Change	Income Inequality Indicator (III) in 2130	% Change	Robberies /Year in 2130	% Change	Culture of crime and violence in 2130	% Change
0	Base case	0.12268126	NA	0.461409748	NA	4636	NA	902.666	NA
1	1	0.164480239	34.071%	0.453317374	-1.754%	4522	-2.464%	900.476	-0.243%
2	2	0.223536968	82.210%	0.455803901	-1.215%	4557	-1.708%	901.156	-0.167%
3	3	0.152126178	24.001%	0.460267872	-0.247%	4620	-0.348%	902.365	-0.033%
4	4	0.132008344	7.603%	0.461094737	-0.068%	4632	-0.096%	902.583	-0.009%
5	5	0.128001645	4.337%	0.461235493	-0.038%	4634	-0.053%	902.620	-0.005%
6	6	0.132167354	7.732%	0.461089671	-0.069%	4632	-0.097%	902.582	-0.009%
7	1 & 2	0.276183933	125.123%	0.443498284	-3.882%	4383	-5.457%	897.663	-0.554%
8	3, 4, 5 & 6	0.175016537	42.660%	0.459094644	-0.502%	4603	-0.705%	902.054	-0.068%
9	1, 3, 4, 5 & 6	0.229828417	87.338%	0.44810155	-2.884%	4448	-4.053%	899.013	-0.405%
10	2, 3, 4, 5 & 6	0.264164448	115.326%	0.452310741	-1.972%	4508	-2.771%	900.192	-0.274%
11	1, 2, 3, 4, 5 & 6	0.32503143	164.940%	0.438011467	-5.071%	4306	-7.128%	896.029	-0.735%

6.3 Policy implications

The aim of this study is to investigate education- and income inequality as a driver of violent property crime in South Africa and apply a knowledge-based approach for developing interventions that address these. From the results of the previous section, the following policy implications regarding violent property crime prevention, are suggested.

The initial increase of robberies caused by interventions, due to initial increases of income inequality, may be subdued with short-term approaches that aim at reducing opportunity of robbery, rather than the motivation for robbery. These interventions may include measures such as increased police visibility and the implementation of neighbourhood patrol organisations.

Scenario 1, representing a 50% reduction of the secondary school dropout rate, exhibited the largest reduction of income inequality and therefore also the largest reduction of robbery among scenarios testing interventions in isolation. When tested in combination with other interventions, the secondary school dropout reduction also generated the largest synergistic effects. Therefore, the results suggest that, amongst the tested interventions, secondary school dropout is the most influential intervention in the system. For this reason, secondary school dropout may be regarded as a considerable long-term intervention point in the fight against violent property crime.

Branson, Hofmeyr and Lam (2014) used the second wave[46] of the National Income Dynamics Study (NIDS) to identify determinants of school dropout in South Africa. Their results indicate that school dropout is significantly larger in secondary school than in primary school (2014: pp. 109-110). The authors found that survey respondents most often stated pregnancy, insufficient funds and work-related responsibilities as the main reasons for dropping out of school before completing Grade 12 (2014: pp. 113-114). This indicates that the application of intervention 1 would require a broad range of strategies to address the various reasons for dropping out of secondary school.

Interventions 2 to 6 increased tertiary education access rates for Grade 12 pupils, from five household income categories, to 50%. The results show progressively lower (albeit small) reductions of robbery for each intervention that targets a higher income category. The discussion, in sub-section 6.2.2, demonstrated that this behaviour pattern occurs due to two reasons. Firstly, the relative population sizes of Grade 12 pupils from the five household income categories mean that increased access for larger populations generate more tertiary education enrolments. Secondly, the different percentage increases of tertiary education access rates applied to Grade 12 pupils from different household income categories mean that higher tertiary education access rate increases, from the current rate, mean more tertiary education enrolments. In other words, the results indicate that the more Grade 12 pupils access tertiary education, the more income inequality is reduced, which in turn generates a larger reduction of robbery incidents over time.

In their study on tertiary education access and success, van Broekhuizen, van der Berg and Hofmeyr (2018) used a nationally representative dataset on Grade 12 learners and university students to determine three major bottlenecks preventing the increase to university access in South Africa. The first bottleneck is the weak progression of Grade 1 learners towards Grade 12 (van Broekhuizen, van der Berg & Hofmeyr, 2018: pp. 81-82). Official enrolment figures indicate that only about 60% of learners who start primary school progress to Grade 12 to write the final National Senior Certificate (NSC) examinations (Van Wyk, 2015). Secondly, only a few of the learners who manage to write the NSC examinations actually achieve a pass mark that makes them eligible for undergraduate studies. Less than 38% and 32% of Grade 12 learners who passed the NSC examinations respectively achieved diploma and bachelor's passes. Thirdly, only a few of those learners who achieve diploma and bachelor passes actually proceed to enrol at university. Only 20% of the 2008 NSC cohort[47]

[46] The National Income Dynamics Study (NIDS) has been repeated every two or three years since 2007. Each interview round is referred to as a "wave". The second wave refers to the interview round conducted in 2010 (Southern Africa Labour and Development Research Unit, 2019).

[47] The 2008 NSC cohort refers to all learners who wrote the 2008 National Senior Certificate (NSC) examinations.

advanced to enrol at public universities between 2009 and 2014 (van Broekhuizen, van der Berg & Hofmeyr, 2018: pp. 81-82).

The results shown in Table 6.6 align with the findings of van Broekhuizen, van der Berg and Hofmeyr (2018). Table 6.6 shows that a combination of all interventions in scenario 11 (entailing a lower secondary school dropout rate with higher tertiary education access for Grade 12 learners from all income categories) generated the greatest increase of tertiary education completion, which in turn produced the greatest decrease of income inequality and therefore the greatest reduction of robbery incidents. As stated by van Broekhuizen, van der Berg and Hofmeyr, many questions regarding tertiary education access in South Africa still remain unanswered. It is still not clear why so many Grade 12 learners who appear to be eligible for university studies do not enter public universities. It is also not yet clear to what extent home backgrounds and financial constraints determine whether learners are able to proceed to university (van Broekhuizen, van der Berg & Hofmeyr, 2018: p. 96). This implies that further research is needed to answer these questions.

Overall, the simulation results suggest that a reduction of robbery incidents through the reduction of income inequality, brought about by increased education levels among South Africans, will require a long time to take effect. However, the findings from this study do suggest that such interventions also generate long-lasting effects which would require a long time to reverse. Additionally, the results indicate that combinations of interventions generate stronger effects than the sum of effects for interventions applied in isolation. Therefore, the interventions discussed may be considered useful for producing long-lasting reductions of income inequality that eventually lead to sustained reductions of robbery. Due to the synergistic effects exhibited by the results, it seems that the discussed interventions would generate more desirable results when applied in combination. This aligns with the argument of Kruger *et al.* (2016: p.62), which maintains that the complexity of crime and violence requires various factors to be taken into account in order to implement integrated and sustained interventions which receive continuous commitment from a range of role players.

6.4 Chapter conclusions

This chapter presented results generated by four key output variables of the simulation model when subjected to scenarios that were aimed at reducing education- and income inequality, in order to reduce annual robbery incidents in South Africa. The results indicate that reductions of secondary school dropout and increases of tertiary education access will eventually lead to decreases of income inequality and therefore also decreases of robbery. It was also found that combinations of the six identified interventions produce synergistic effects. This suggests that a collaborative approach should be applied to South African robbery prevention in order to produce the greatest results. Additionally, it was found that the identified interventions only produce considerable reductions of robbery after a long while of implementation. However, due to the strong inertia brought about by these interventions, the effects would be long-lasting. Therefore, it may be concluded that sustained reductions of secondary school dropout and sustained increases of tertiary education access may produce long-lasting reductions of income inequality and therefore also long-lasting reductions of robbery in South Africa. As this approach only targets one of the currently identified factors sustaining the criminal and violent culture in South Africa, it should be considered as part of a collaborative strategy in the fight against violent property crime.

CHAPTER 7

Conclusion

Contents

Experience is an expensive school. – Benjamin Franklin

The preceding chapters dealt with specific elements of the study in detail. This chapter describes the overall results from the study and provides several conclusions which may be derived from these results. Firstly, section 7.1 provides an overview of the study's findings. Then the study's most important limitations are pointed out in section 7.2. Next, section 7.3 provides several conclusions which may be derived from the findings described in section 7.1. Lastly, future research avenues, based on the study's limitations, are recommended in section 7.4.

7.1 Summary of findings

Chapter 1 introduced the problem investigated by this study. It was discussed that interventions for reducing crime in South Africa have been implemented as well as changed in the past. In general, annually recorded community-reported crime has decreased gradually over the last twelve years. However, recorded incidents of robbery at residential- and non-residential premises in South Africa have risen during the same time span.

Along with the research scope, the research aim was defined as an attempt to investigate core drivers of robbery in the context of South African education- and income inequality, by means of system dynamics, in order to identify and test appropriate interventions. Six research objectives were then defined. Chapters 3 to 6 described, in detail, how these objectives were reached. Several findings may be reported from these chapters.

Chapter 3 described the design of- and results produced by a scoping literature review that was conducted to create an overview of- and generate insight from existing mathematical models that have been created to study crime. The review revealed that mathematical models of crime consist mainly of agent-based models and analytical models. System dynamics (SD) models of crime form a minority within the reviewed group of mathematical crime models. Of these SD models, only two were developed in the context of South Africa and neither of these two had a specific focus on robbery. Among the reviewed literature on SD models, only one model was found to have been rigorously validated according to methods suggested by Forrester and Senge (1980) and Barlas (1989). In summary then, the results of the review indicate a lack of literature concerned with rigorously validated system dynamics models studying robbery within the South African context.

Chapter 4 presented a conceptual literature review regarding drivers of robbery in South Africa, as well as criminological theory relating to these. A definition and contextualisation of South African robbery revealed that this type of crime may be classified as violent property crime. One of the aforementioned drivers for violent crime in South Africa is inequality. As the scope of this study is aligned with the priorities set out in the 2030 National Development Plan, the search for drivers of South African robbery was focussed on inequality. Within the context of inequality it was shown that, among other types of inequality, South Africa has been- and is experiencing high income inequality. Literature concerned with the roots of South African income inequality then revealed a considerable relationship between education levels and household income. Additionally, an investigation of literature on criminological theories revealed that the causal relationship between inequality and crime is advocated by three main ecological theories of crime. Research seeking empirical support for these theories has produced some support, but the relationships are usually not strong. On the other hand, research investigating the link between inequality and crime, which may be derived from the description of anomie/strain theories, has found stronger support. Most of this research has focussed on the United States of America, but the study of Demombynes and Özler (2005) provides evidence that the relationship between crime and inequality also exists in South Africa.

Chapter 5 described the dynamic hypothesis developed from the arguments found in Chapter 4. The dynamic hypothesis consists of three sub-models representing education levels, household income categories and incidents of robbery in South Africa. Eight of the twelve model validation tests described by Sterman (2000: pp. 858-891) were used to determine the level of confidence one can have in the results of the simulation model. From the results of these tests, various assumptions and simplifications were identified and it was broadly concluded that the simulation model may be considered adequate, but not perfect, for the purpose at hand.

Chapter 6 presented some results generated by the model. Six interventions for robbery prevention, in the context of South African education- and income inequality, were described. These were aimed at reducing secondary school dropout and increasing tertiary education access to Grade 12 pupils from the different household income categories. From these interventions, eleven scenarios were developed to test the effect brought about by these interventions in isolation and in specific combinations. The results from these scenarios were discussed and corresponding implications for policy were described.

7.2 Critical reflection and limitations

As is the case for any study, this study exhibits several limitations that should be kept in mind when interpreting the generated results. This section describes the main limitations of the developed simulation model which were identified at the model testing phase.

Due to the narrow scope of the study, the model boundary was also narrowly defined. Additionally, various simplifications were imposed due to the constraints of the study. A significant simplification was imposed by only accounting for undergraduate degrees and diplomas of NQF levels 6, 7 and 8 obtained from South African universities at the tertiary education level. The inclusion of AET and FET colleges, as well as postgraduate qualifications might provide insight to the effect brought about by different kinds of post-school qualifications.

The income sub-model only allows for five income categories to be presented. The discussions in sub-sections 5.3.4 and 6.2.1 point out that this simplification has implications on the accuracy of the Income Inequality Indicator (III) calculated by the model. Another crucial assumption made from the income sub-model is the exclusion of availability of jobs related to the education levels. The relationship between education-level and income level is presented through ratios calculated from data obtained by the General Household Surveys conducted between 2009 and 2018.

The brief list of theories identified through the scoping literature review, as mentioned in sub-section 4.2.4, indicates that various factors play a role in a potential offender's decision-making process. However, the focus of the study is income inequality and therefore income inequality is the main factor that influences this decision-making process in the model. Additionally, due to the scope of the study, the model boundary excludes the influences of types of strain other than income inequality.

The model is represented at a national level due to inadequate access to data at lower aggregation levels. A lower level of aggregation at provincial or municipal levels would allow more accurate representations of the real system. The development of the model at a national level does, however, produce an indication of the system's behaviour as a whole without having to spend more resources on modelling all provinces or municipal areas.

The behaviour reproduction test showed that the model does not precisely reproduce the behaviour of the available reference modes. The model was calibrated to achieve the best possible fit for all parameters that do have reference modes. The outcome is that the model's parameters do not exactly replicate, but rather follow the general trends that the reference modes exhibit. Additionally, no reference modes exist for the crime sub-model. Parameters such as *incidents of robbery due to household income inequality strain* and the *culture of crime and violence* in South Africa have not been recorded in the past. Measuring these does seem to pose various difficulties. Therefore, no reference modes are available for these parameters. Nevertheless, the behaviour of these parameters was judged to be adequately realistic for the model's intended purpose.

The sensitivity analysis described in sub-section 5.4.8 revealed that the model contains several highly uncertain parameters which are also significantly influential regarding the model's four key output parameters. Therefore, the model exhibits considerable numerical sensitivity. Additionally, it was found that the model does exhibit slight behaviour mode sensitivity at the beginning of the simulation period. This therefore calls for further parameter estimation. Policy sensitivity was not tested for. This may also be performed in the future to gain a better understanding of the range of uncertainties that exist regarding results generated by the tested interventions.

7.3 Study conclusions

Several conclusions can be drawn from the findings described in the previous section. Initially, the scoping review indicated a gap in literature concerned with rigorously validated system dynamics models of robbery within the South African context. This study therefore addresses this literature gap.

Moreover, the conceptual literature review provided additional insights. A closer look at crime classification revealed that robbery may be classified as violent property crime in South Africa. Literature on causes of violent crime in South Africa suggests that a culture of crime and violence is the core problem of violent crime in South Africa and that inequality is one of the factors that sustains this culture (CSVR, 2010: pp. 50-52). Among other types of inequality, income inequality as measured by the Gini coefficient is especially high in South Africa. Literature investigating causes for South Africa's high income-inequality suggest unequal education levels among South Africans is a major factor. From these findings of the reviewed literature, it was deduced that undergraduate access rates of South African learners are strongly related to their respective neighbourhood wealth quintiles.

Upon investigating criminological theories, it was found that three of the theories identified through the scoping literature review advocated the relationship between inequality and crime. Rather than substitutes, these three theories should be seen as complementary, where each theory focuses on a different aspect of the link between inequality and crime (Kelly, 2000: pp. 530-531). Researchers who look for empirical evidence for these specific theories have found some support for their hypotheses, but the relationships are usually not strong (Akers, Sellers & Jennings, 2017: pp. 205-206). However, research investigating the link between inequality and crime has found more compelling evidence. Most of the mentioned research that found stronger support for this relationship was conducted in the context of the United States of America. However, one study by Demombynes and Özler (2005) focused on South Africa. Their results agree with sociological theories which argue that inequality leads to crime in general, and also agree with economic theories that associate inequality with property crime. Therefore, it may be concluded that the relationship between inequality and crime also exists in South Africa.

The results generated by the simulation model should be interpreted whilst keeping in mind all of the limitations that were identified through model testing. Chapter 6 presented robbery prevention interventions aimed at increasing South African education levels, in order to reduce the current high level of income inequality. This was simulated by decreasing secondary school dropout and increasing tertiary education access in South Africa. Overall, the simulation results suggest that a reduction of robbery incidents through the above-mentioned interventions will require a long time to produce a considerable effect. However, the results do suggest that such interventions also generate long-lasting effects which would require a long time to reverse. Furthermore, the results indicate that combinations of interventions generate stronger effects than the sum of effects produced by interventions applied in isolation.

Therefore, it may be concluded that sustained reductions of secondary school dropout and sustained increases of tertiary education access may produce long-lasting reductions of income inequality and therefore also long-lasting reductions of robbery (and possible other crimes) in South Africa. Due to the synergistic effects exhibited by the results, it seems that the discussed interventions would generate more desirable results when applied in combination. This aligns with the argument of Kruger *et al.* (2016: p. 62), which states that the complexity of crime and violence requires various factors to be taken into account in order to implement integrated and sustained interventions. The approach of this study only targets one of the currently identified factors sustaining the criminal and violent culture in South Africa, namely inequality. Therefore, this approach should only be considered as forming part of a collaborative and long-term strategy in the fight against violent property crime within South Africa.

7.4 Future research

As pointed out by Sterman, all models are wrong and differ from reality in many ways (Sterman, 2000: p. 846). Section 7.2 highlights various limitations of the study which already point towards areas of improvement. The following is a brief description of suggested future research avenues which may improve the model's ability to represent reality and therefore allow users to make better informed decisions.

Suggestion 1: *Including other post-school qualifications*

As mentioned before, the model only accounts for undergraduate degrees and NQF level 6, 7 and 8 diplomas obtained from South African universities. This means that the model only considers a certain portion of post-school education in South Africa. It may be useful to include qualifications from AET and FET colleges. This may allow a comparison of income inequality reduction capabilities of different qualifications and levels of education.

Suggestion 2: *Making use of data collected through the National Income Dynamics Study (NIDS)*

The reference modes regarding education level and income range for South Africans was derived from data collected through the General Household Surveys (GHS) and the Quarterly Labour Force Surveys (QLFS). These surveys generate data from annual samples that differ every year. In contrast, the NIDS is a panel study that, since 2008, has followed the lives of the same 28,000 South Africans and those with whom they live. The data collected from this study may generate more accurate reference modes when used in combination with the GHS and QLFS.

Suggestion 3: *Accounting for more income categories with different ranges*

As explained in sub-section 5.3.3, the income model only accounts for five income categories. The categories are arranged in R5,000 intervals. The highest category accounts for households with an average monthly income of R20,000 and more. These few categories with fairly large equal ranges only allow for a crude estimation of income inequality. It was previously shown in Figure 4.5 that in 2015, the poorest 40% of the South African population received around 11% of annual income. On the other hand, the richest 10% of the population received around 41% of the annual income share. The estimation of income inequality may therefore be improved through the creation of more income categories with different ranges. Due to the high proportion of South Africans that form part of the lowest income group, income inequality may be more accurately represented when incorporating more income categories with smaller ranges at the lower end of the income spectrum. Due to the small proportion of South Africans who form part of the highest income group, income inequality may be more accurately captured when more income categories with larger ranges are created at the higher end of the income spectrum.

Suggestion 4: *Accounting for job availability*

Currently the distribution of South Africans among the income categories is mainly influenced by ratios that relate education levels with income levels and partly influenced by upward- and downward mobility rates. The model does therefore not account for the availability of jobs related to each education level. Incorporating qualification-based labour demand may yield additional insights regarding the relation between education and household income.

Suggestion 5: *Defining the model at a lower aggregation level*

The model's current national level of aggregation allows the generation of high-level insights regarding the research problem. However, a lower level of aggregation at provincial or municipal level may generate more specific insights for a certain area. Therefore, it is suggested that a lower aggregation level is used when considering this model for robbery prevention strategies for specific provincial or municipal areas of South Africa.

Suggestion 6: *Further estimation of uncertain and influential parameters*

The sensitivity analysis described in sub-section 5.4.8 revealed that the model contains several parameters that are highly uncertain, as well as significantly influential regarding the model's four key output variables. The multivariate sensitivity analysis showed that the model does exhibit a considerable range of numerical sensitivity, as well as slight initial behaviour mode sensitivity. Therefore, it is suggested that attention should be directed towards further estimation of these parameters.

Suggestion 7: *Performing policy sensitivity analysis*

Policy sensitivity analysis was not performed during the study. Testing for policy sensitivity may indicate whether changes in assumptions, brought about by the current level of uncertainty of influential parameters, reverses the impact or desirability of a proposed policy. If this is the case, it is another indication that the uncertain parameters need to be estimated more accurately. Additionally, policy sensitivity analysis may be used to test whether changes of the current model boundary have a significant effect on the outcome of proposed interventions.

7.5 Chapter conclusion

The final chapter of the study provided an overview of the generated results and the conclusions that can be drawn from them. Firstly, the findings of the study were summarised and some of the more important limitations of the study were pointed out. Thereafter, conclusions which may be drawn from the study's results were presented. Lastly, some future research avenues were suggested, based on the study's limitations.

Bibliography

Abounoori, E. and McCloughan, P. (2003) ‘A simple way to calculate the Gini Coefficient for grouped as well as ungrouped data’, *Applied Economics Letters*, 10(8), pp. 505–509. Available at: https://doi.org/10.1080/1350485032000100279 (Accessed: 22 October 2020).

Adekoya, A. F. (2019) ‘Income Inequality and Violent Crime in Nigeria: A Panel Corrected Standard Error Approach’, *Ibadan Journal of Peace & Development*, 9(2), pp. 1–10. Available at: http://ijpd.org/index.php/ipjd/article/view/79 (Accessed: 13 November 2020).

Africa GeoPortal (2019) *Average Household Size in South Africa*. Available at: https://www.africageoportal.com/datasets/582208ececa2424ab6e387d9cdcf01e3 (Accessed: 15 August 2019).

Agnew, R. (1992) ‘Foundation for a general strain theory of crime and delinquency’, *Criminology*, 30(1), pp. 47–88.

Agnew, R. and Scheuerman, H. (2011) ‘Strain Theories’, *Oxford Bibliographies Online*. Available at: https://www.oxfordbibliographies.com/view/document/obo-9780195396607/obo-9780195396607-0005.xml (Accessed: 14 June 2019).

Akers, R. L. (1999) *Criminological theories: introduction and evaluation*. second edi. Edited by R. L. Akers. Chicago, USA: Fitzroy Dearborn Publishers.

Akers, R. L., Sellers, C. S. and Jennings, W. G. (2017) *Criminological theories: introduction, evaluation, and application*. 7th edn. New York: Oxford University Press.

Albanese, J. S. (2009) ‘Organized Crime’, *Oxford Bibliographies Online*. Available at: https://www.oxfordbibliographies.com/view/document/obo-9780195396607/obo-9780195396607-0021.xml (Accessed: 16 June 2019).

Andersen, D. L. *et al.* (2012) ‘The disconfirmatory interview as a strategy for the assessment of system dynamics models’, *System Dynamics Review*, 28(3), pp. 255–275. Available at: http://doi.wiley.com/10.1002/sdr.1479 (Accessed: 3 April 2018).

Andresen, M. A. (2013) ‘Unemployment, business cycles, crime, and the Canadian provinces’, *Journal of Criminal Justice*, 41(4), pp. 220–227. Available at: https://doi-org.ez.sun.ac.za/10.1016/j.jcrimjus.2013.05.006 (Accessed: 14 November 2020).

Anser, M. K. *et al.* (2020) ‘Dynamic linkages between poverty, inequality, crime, and social expenditures in a panel of 16 countries: two-step GMM estimates’, *Journal of Economic Structures*, 9(43), pp. 1–25. Available at: https://doi.org/10.1186/s40008-020-00220-6 (Accessed: 13 November 2020).

Antwi Bosiakoh, T. (2012) ‘Differential Association Theory’, *Encyclopedia of the Sciences of Learning*. Springer, Boston, MA. Available at: https://doi.org/10.1007/978-1-4419-1428-6_1869 (Accessed: 6 September 2019).

Arcaya, M. C., Arcaya, A. L. and Subramanian, S. V. (2015) ‘Inequalities in health: definitions, concepts, and theories’, *Global Health Action*, 8(27106). Available at: https://doi.org/10.3402/gha.v8.27106 (Accessed: 10 November 2020).

Arksey, H. and O’Malley, L. (2005) ‘Scoping studies: towards a methodological framework’, *International Journal of Social Research Methodology*, 8(1), pp. 19–32. Available at: https://doi.org/10.1080/1364557032000119616 (Accessed: 16 November 2020).

Astarita, C., Capuano, C. and Puri, F. (2018) ‘The macroeconomic impact of organised crime : A post-Keynesian analysis’, 68, pp. 514–528. Available at: https://doi.org/10.1016/j.econmod.2017.08.029 (Accessed: 20 May 2018).

Atkinson, A. B. (1970) ‘On the measurement of inequality’, *Journal of economic theory*, 2(3), pp. 244–263.

Barlas, Y. (1989) ‘Multiple tests for validation of system dynamics type of simulation models’, *European Journal of Operational Research*. North-Holland, 42(1), pp. 59–87. Available at: https://www.sciencedirect.com/science/article/pii/0377221789900593?via%3Dihub (Accessed: 20 August 2019).

Barlas, Y. (1990) ‘An autocorrelation function test for out put validation’, *Simulation*, 55(1), pp. 7–16.

Barlas, Y. (1996) ‘Formal aspects of model validity and validation in system dynamics’, *System Dynamics Review: The Journal of the System Dynamics Society*, 12(3), pp. 183–210.

Becker, G. S. (1968) ‘Crime and Punishment: An Economic Approach’, *Journal of Political Economy*, 76(2), pp. 169–217.

van der Berg, S. (2002) ‘Education, poverty and inequality in South Africa’, in *Paper to the conference of the Centre for the Study of African Economies on Economic Growth and Poverty in Africa*. Oxford, March, pp. 1–26.

Birks, D. and Davies, T. (2017) ‘Street Network Structure and Crime Risk : an Agent-Based Investigation of the Encounter and Enclosure Hypotheses’, *Criminology*, 55(4), pp. 900–937. Available at: https://doi.org/10.1111/1745-9125.12163 (Accessed: 2 September 2019).

Blau, J. R. and Blau, P. M. (1982) ‘The cost of inequality: Metropolitan structure and violent crime’, *American Sociological Review*, 47(February), pp. 114–129.

Boggess, L. N. and Hipp, J. R. (2016) ‘The Spatial Dimensions of Gentrification and the Consequences for Neighborhood Crime’, *Justice Quarterly*, 33(4), pp. 584–613.

Borshchev, A. and Filippov, A. (2004) ‘From System Dynamics and Discrete Event to Practical Agent Based Modeling: Reasons, Techniques, Tools’, *Simulation*, 66(11), pp. 25–29.

Branson, N. *et al.* (2015) ‘Post-school education: Broadening alternative pathways from school to work’, in De Lannoy, A. et al. (eds) *South African Child Gauge 2015*. 2015th edn. Cape Town: Children’s Institute, University of Cape Town, pp. 42–49. Available at: http://www.hr.uct.ac.za/sites/default/files/image_tool/images/367/Child_Gauge/South_African_Child_Gauge_2015/Child_Gauge_2015-Post-schooling.pdf (Accessed: 15 June 2018).

Branson, N., Hofmeyr, C. and Lam, D. (2014) ‘Progress through school and the determinants of school dropout in South Africa’, *Development Southern Africa*, 31(1), pp. 106–126.

Brantingham (1981) *Environmental criminology*. Edited by P. J. Brantingham and P. L. Brantingham. Beverly Hills, California: Sage Publications.

Brantingham, P. L. (2010) ‘Crime Pattern Theory’, in *Encyclopedia of Victimology and Crime Prevention*. Thousand Oaks, California: SAGE Publications, Inc., pp. 193–198.

Breetzke, G. and Horn, A. (2008) ‘Key requirements in the development of a spatial-ecological theory of crime in South Africa’, *Acta Criminologica: Southern African Journal of Criminology*, 21(1), pp. 123–143.

van Broekhuizen, H., van der Berg, S. and Hofmeyr, H. (2016) *Higher Education Access and Outcomes for the 2008 National Matric Cohort*. Stellenbosch Economic Working Papers: 16/16. Stellenbosch. Available at: https://www.ekon.sun.ac.za/wpapers/2016/wp162016/wp-16-2016_1.pdf (Accessed: 20 October 2019).

van Broekhuizen, H., van der Berg, S. and Hofmeyr, H. (2018) 'From Grade 12 into, and through, university: Higher education access and success for the 2008 national NSC cohort', in Rogan, M. (ed.) *Post-school education and the labour market in South Africa*. Cape Town: HSRC Press, pp. 79–99.

Burchell, J. M. (2005) *Principles of criminal law*. 3rd ed. Edited by J. Milton. Lansdowne, South Africa: Juta.

Bursik, R. J. (1988) 'Social disorganization and theories of crime and delinquency: Problems and prospects', *Criminology*, 26(4), pp. 519–551. Available at: http://www.personal.psu.edu/exs44/597b-Comm&Crime/Bursik - Soc Disorg.pdf (Accessed: 12 November 2020).

Cacchione, P. Z. (2016) 'The Evolving Methodology of Scoping Reviews', *Clinical Nursing Research*, 25(2), pp. 115–119. Available at: https://doi-org.ez.sun.ac.za/10.1177%2F1054773816637493 (Accessed: 16 November 2020).

Calvó-Armengol, A., Verdier, T. and Zenou, Y. (2007) 'Strong and weak ties in employment and crime', *Journal of Public Economics*, 91(1–2), pp. 203–233.

Carney, T. *et al.* (2013) 'The relationship between substance use and delinquency among high-school students in Cape Town, South Africa', *Journal of Adolescence*, 36(3), pp. 447–455. Available at: https://doi-org.ez.sun.ac.za/10.1016/j.adolescence.2013.01.004 (Accessed: 14 November 2020).

Charles-Coll, J. A. (2011) 'Understanding Income Inequality: Concept , Causes and Measurement', *International Journal of Economics and Management Sciences*, 1(3), pp. 17–28.

Chen, H., Cheng, T. and Wise, S. (2017) 'Developing an online cooperative police patrol routing strategy', *Computers, Environment and Urban Systems*, 62, pp. 19–29.

Cheteni, P., Mah, G. and Yohane, K. Y. (2018) 'Drug-related crime and poverty in South Africa', *Cogent Economics & Finance*, 6(1), p. 1534528. Available at: https://doi.org/10.1080/23322039.2018.1534528 (Accessed: 14 November 2020).

Civilian Secretariat for Police (2016) *2016 White Paper on Safety and Security*. Available at: http://www.policesecretariat.gov.za/legislation/whitepaper.php (Accessed: 10 June 2018).

Cohen, L. E. and Felson, M. (1979) 'Social Change and Crime Rate Trends : A Routine Activity Approach', *American Sociological Review*, 44(4), pp. 588–608. Available at: https://www.jstor.org/stable/2094589 (Accessed: 7 April 2019).

Colman, A. M. and Krockow, E. M. (2017) 'Game Theory and Psychology', *Oxford Bibliographies Online*. Available at: https://www.oxfordbibliographies.com/view/document/obo-9780199828340/obo-9780199828340-0192.xml (Accessed: 15 June 2019).

Coyle, G. and Exelby, D. (2000) 'The validation of commercial system dynamics models', *System Dynamics Review: The Journal of the System Dynamics Society*, 16(1), pp. 27–41.

Crush, J. and McDonald, D. A. (2000) 'Transnationalism, African Immigration, and New Migrant Spaces in South Africa: An Introduction', *Canadian Journal of African Studies*, 34(1), pp. 1–19.

CSVR (2007) *The Violent Nature of Crime in South Africa: A concept paper for the Justice, Crime Prevention and Security Cluster*. Braamfontein, South Africa. Available at: https://www.csvr.org.za/publications/1503-the-violent-nature-of-crime-in-south-africa--a-concept-paper-prepared-for-the-justice-crime-prevention-and-security-cluster (Accessed: 4 June 2018).

CSVR (2010) *Tackling Armed Violence: key findings and recommendations of the study on the violent nature of crime in South Africa*. Braamfontein, South Africa. Available at: https://www.csvr.org.za/docs/study/6.TAV_final_report_13_03_10.pdf (Accessed: 21 February 2019).

Danziger, S. (1976) 'Explaining Urban Crime Rates', *Criminology*, 14(2), pp. 291–296.

Demombynes, G. and Özler, B. (2005) 'Crime and local inequality in South Africa', *Journal of Development Economics*, 76(2), pp. 265–292.

Department for Basic Education South Africa (2008) *School Realities 2008*. Available at: https://www.education.gov.za/Programmes/EMIS/StatisticalPublications.aspx (Accessed: 5 May 2018).

Department for Basic Education South Africa (2009) *School Realities 2009*. Available at: https://www.education.gov.za/Programmes/EMIS/StatisticalPublications.aspx (Accessed: 5 May 2018).

Department for Basic Education South Africa (2010) *School Realities 2010*. Available at: https://www.education.gov.za/Programmes/EMIS/StatisticalPublications.aspx (Accessed: 5 May 2018).

Department for Basic Education South Africa (2011) *School Realities 2011*. Available at: https://www.education.gov.za/Programmes/EMIS/StatisticalPublications.aspx (Accessed: 5 May 2018).

Department for Basic Education South Africa (2012) *School Realities 2012*. Available at: https://www.education.gov.za/Programmes/EMIS/StatisticalPublications.aspx (Accessed: 5 May 2018).

Department for Basic Education South Africa (2013) *School Realities 2013*. Available at: https://www.education.gov.za/Programmes/EMIS/StatisticalPublications.aspx (Accessed: 5 May 2018).

Department for Basic Education South Africa (2014) *School Realities 2014*. Available at: https://www.education.gov.za/Programmes/EMIS/StatisticalPublications.aspx (Accessed: 5 May 2018).

Department for Basic Education South Africa (2015) *School Realities 2015*. Available at: https://www.education.gov.za/Programmes/EMIS/StatisticalPublications.aspx (Accessed: 5 May 2018).

Department for Basic Education South Africa (2016) *School Realities 2016*. Available at: https://www.education.gov.za/Programmes/EMIS/StatisticalPublications.aspx (Accessed: 5 May 2018).

Department for Basic Education South Africa (2017) *School Realities 2017*. Available at: https://www.education.gov.za/Programmes/EMIS/StatisticalPublications.aspx (Accessed: 5 May 2018).

Department for Basic Education South Africa (2019) *School Realities 2018*. Available at: https://www.education.gov.za/Programmes/EMIS/StatisticalPublications.aspx (Accessed: 17 June 2019).

Deutsch, S. J. and Malmborg, C. J. (1985) 'A dynamic model to forecast incapacitation and deterrence effects', *Applied Mathematical Modelling*, 9(1), pp. 53–61.

Devia, N. and Weber, R. (2013) 'Generating crime data using agent-based simulation', *Computers, Environment and Urban Systems*, 42, pp. 26–41.

Doren, B. and Benz, M. R. (1998) 'Employment Inequality Revisisted: predictors of better employment outcomes for young women with disabilities in transition', *The Journal of Special Education*, 31(4), pp. 425–442.

Durkheim, E. (1897) *Le suicide: Étude de sociologie [On suicide]*. Paris: Presses Universitaires de

France.

Durkheim, E. (1951) *Suicide: a study in sociology*. Glencoe, Illinois: Free Press.

van Dyk, H. and White, C. (2019) 'Theory and practice of the quintile ranking of schools in South Africa: A financial management perspective', *South African Journal of Education*, 39(1), pp. 1–9. Available at: https://doi.org/10.15700/saje.v39ns1a1820 (Accessed: 13 November 2020).

Elsenbroich, C. (2017) 'The Addio Pizzo movement : exploring social change using agent-based modelling', *Trends in organized crime*, 20, pp. 120–138.

Enamorado, T. *et al.* (2016) 'Income inequality and violent crime: Evidence from Mexico's drug war', *Journal of Development Economics*, 120, pp. 128–143. Available at: https://doi.org/10.1016/j.jdeveco.2015.12.004 (Accessed: 13 November 2020).

Fajnzylber, P., Lederman, D. and Loayza, N. (2002a) 'Inequality and Violent Crime', *The Journal of Law & Economics*, 45(1), pp. 1–39.

Fajnzylber, P., Lederman, D. and Loayza, N. (2002b) 'What causes violent crime?', *European Economic Review*, 46(7), pp. 1323–1357.

Finn, A. and Leibbrandt, M. (2016) *The dynamics of poverty in the first four waves of NIDS*. SALDRU Working Paper Number 174/ NIDS Discussion Paper 2016/1. Cape Town: SALDRU, University of Cape Town.

Ford, A. (2009) *Modeling the environment*. Second edi. Washington, DC: Island Press.

Forrester, J. W. (1961) *Industrial dynamics.* Cambridge, Mass: M.I.T. Press.

Forrester, J. W. (1973) 'Confidence in Models of social behaviour – With emphasis on System Dynamics Models', *MIT System Dynamics Group Memo D-1967*. Cambridge, MA 02139 (unpublished).

Forrester, J. W. and Senge, P. M. (1980) 'Tests for building confidence in system dynamics models', *System dynamics, TIMS studies in management sciences*, 14, pp. 209–228.

Furtado, V. *et al.* (2009) 'A bio-inspired crime simulation model', *Decision Support Systems*, 48(1), pp. 282–292.

Garoupa, N. (2014) 'Economic Theory of Criminal Behavior', *Encyclopedia of Criminology and Criminal Justice*. Edited by G. Bruinsma and D. Weisburd. New York, NY: Springer New York.

Ghaffarzadegan, N., Lyneis, J. and Richardson, G. P. (2011) 'How small system dynamics models can help the public policy process', *System Dynamics Review*, 27(1), pp. 22–44.

Ghaffarzadegan, N., Lyneis, J. and Richardson, G. P. (2015) 'Policy Informatics with Small System Dynamics Models: How Small Models Can Help the Public Policy Process', *Governance in the information Era: Theory and practice of policy informatics*, 27(1), pp. 144–160.

Gilbert, L. and Walker, L. (2002) 'Treading the path of least resistance: HIV/AIDS and social inequalities - A South African case study', *Social Science and Medicine*, 54(7), pp. 1093–1110.

Gini, C. (1912) 'Variabilità e mutabilità', *Reprinted in Memorie di metodologica statistica (Ed. Pizetti E, Salvemini, T). Rome: Libreria Eredi Virgilio Veschi*.

Glaser, C. (2008) 'Violent Crime in South Africa: Historical Perspectives', *South African Historical Journal*, 60(3), pp. 334–352.

Goold, M. and Campbell, A. (1998) 'Desperately seeking synergy', *Harvard business review*, 76(5), pp. 131–143.

Grant, M. J. and Booth, A. (2009) ‘A typology of reviews: an analysis of 14 review types and associated methodologies’, *Health Information & Libraries Journal*, 26(2), pp. 91–108.

Grigoryev, I. (2015) *AnyLogic 7 in Three Days: A Quick Course in Simulation Modeling*. 3rd edn. CreateSpace Independent Publishing Platform.

Haas, T. C. and Ferreira, S. M. (2016) ‘Combating Rhino Horn Trafficking : The Need to Disrupt Criminal Networks’, *PLoS ONE*, 11(11), pp. 1–26.

Harris, G. and Vermaak, C. (2015) ‘Economic inequality as a source of interpersonal violence: Evidence from Sub-Saharan Africa and South Africa’, *South African Journal of Economic and Management Sciences*, 18(1), pp. 45–57. Available at: https://dx.doi.org/10.17159/2222-3436/2015/v18n1a4 (Accessed: 9 November 2020).

Hipp, J. R. *et al.* (2013) ‘Extrapolative simulation of neighborhood networks based on population spatial distribution : Do they predict crime ?’, *Social Networks*, 35(4), pp. 614–625.

Holt, T. (2009) ‘Social Learning Theory’, *Oxford Bibliographies Online*. Available at: https://www.oxfordbibliographies.com/view/document/obo-9780195396607/obo-9780195396607-0002.xml (Accessed: 23 May 2020).

Hsieh, C.-C. and Pugh, M. D. (1993) ‘Poverty, income inequality, and violent crime: a meta-analysis of recent aggregate data studies’, *Criminal Justice Review*, 18(2), pp. 182–202.

Hwang, Y. *et al.* (2017) ‘Predicting residential burglaries based on building elements and offender behavior: Study of a row house area in Seoul , Korea’, *Computers, Environment and Urban Systems*, 61, pp. 94–107.

IDSC (no date) *Student Headcount by Qualification Type (HEDA Viewer)*. Available at: https://www.heda.co.za/PowerHEDA/forms/admin/customreports/customReportDataViewer.aspx?pk=52 (Accessed: 19 March 2019).

Jacobs, D. (1981) ‘Inequality and Economic Crime’, *Sociology and Social Research*, 66(1), pp. 12–28.

Jaén, S. and Dyner, I. (2008) ‘Criminal Cycles in the Illegal Drug Industry: a System Dynamics Approach Applied to Colombia’, in Mason, S. J. et al. (eds) *Proceedings of the 2008 Winter Simulation Conference*. Miami, FL, USA, pp. 1429–1436.

Jaén, S. and Dyner, I. (2014) ‘A system dynamics approach to the study of Colombian coca cultivation and the counter-intuitive consequence of law enforcement’, *International Journal of Drug Policy*, 25(2), pp. 226–234.

Jewkes, R. *et al.* (2011) ‘Gender Inequitable Masculinity and Sexual Entitlement in Rape Perpetration South Africa: Findings of a Cross-Sectional Study’, *PLoS ONE*, 6(12), pp. 1–11. Available at: https://doi.org/10.1371/journal.pone.0029590 (Accessed: 15 November 2020).

Joanna Briggs Institute (2015) *Joanna Briggs Institute Reviewers’ Manual: 2015 edition / Supplement*. South Australia, Australia: The Joanna Briggs Institute. Available at: https://nursing.lsuhsc.edu/JBI/docs/ReviewersManuals/Scoping-.pdf (Accessed: 16 November 2020).

Julong, D. (1989) ‘Introduction to grey system’, *The Journal of Grey System*, 1, pp. 1–24.

Kalmijn, W. (2014) ‘Gini Coefficient’, in Michalos, A. C. (ed.) *Encyclopedia of Quality of Life and Well-Being Research*. Dordrecht: Springer Netherlands, pp. 2559–2561. Available at: https://doi.org/10.1007/978-94-007-0753-5_1168 (Accessed: 3 July 2019).

Kelly, M. (2000) ‘Inequality and Crime’, *The Review of Economics and Statistics*, 82(4), pp. 530–539.

Kruger, T. *et al.* (2016) *Making South Africa Safe: A Manual for Community-based Crime Prevention*. Pretoria, SA: The Council for Scientific and Industrial Research (CSIR). Available at: https://www.csir.co.za/sites/default/files/Documents/Making South Africa Safe.pdf (Accessed: 5 February 2019).

Law, A. M. and Kelton, W. D. (2000) *Simulation modeling and analysis*. 3rd edn. Boston: McGraw-Hill.

Lederman, D., Loayza, N. and Menéndez, A. M. (2002) 'Violent Crime: Does Social Capital Matter?', *Economic Development and Cultural Change*, 50(3), pp. 509–539.

Levac, D., Colquhoun, H. and O'Brien, K. K. (2010) 'Scoping studies: advancing the methodology', *Implementation Science*, 5(69), pp. 1–9. Available at: https://doi.org/10.1186/1748-5908-5-69 (Accessed: 16 November 2020).

Liu, S., Forrest, J. and Yang, Y. (2012) 'A brief introduction to grey systems theory', *Grey Systems: Theory and Application*, 2(2), pp. 89–104.

Liu, W., Beacom, A. M. and Valente, T. (2017) 'Social Network Theory', *The International Encyclopedia of Media Effects*. John Wiley & Sons, Inc. Available at: https://doi.org/10.1002/9781118783764.wbieme0092 (Accessed: 9 June 2018).

Lorenz, M. O. (1905) 'Methods of Measuring the Concentration of Wealth', *Publications of the American Statistical Association*, 9(70), pp. 209–219.

Luna-Reyes, L. F., Diker, V. and Andersen, D. L. (2012) 'Interviewing as a Strategy for the Assessment of System Dynamics Models', *SSRN Electronic Journal*. Available at: https://dx.doi.org/10.2139/ssrn.2122111 (Accessed: 5 June 2018).

Maani, K. E. and Cavana, R. Y. (2007) *Systems Thinking, System Dynamics: Managing Change and Complexity*. Second edi. Edited by N. Lampon. Auckland: Pearson Education New Zealand.

De Maio, F. G. (2007) 'GLOSSARY: Income inequality measures', *Journal of Epidemiology and Community Health*, 61(10), pp. 849–852. Available at: https://www.jstor.org/stable/40665665 (Accessed: 11 November 2020).

Makanga, P. T., Schuurman, N. and Randall, E. (2017) 'Community perceptions of risk factors for interpersonal violence in townships in Cape Town, South Africa: A focus group study', *Global Public Health*, 12(10), pp. 1254–1268. Available at: https://doi.org/10.1080/17441692.2015.1123751 (Accessed: 14 November 2020).

Malleson, N. and Birkin, M. (2012) 'Computers , Environment and Urban Systems Analysis of crime patterns through the integration of an agent-based model and a population microsimulation', *Computers, Environment and Urban Systems*, 36, pp. 551–561.

Malleson, N., Heppenstall, A. and See, L. (2010) 'Crime reduction through simulation : An agent-based model of burglary', *Computers, Environment and Urban Systems*, 34(3), pp. 236–250.

Manaliyo, J.-C. (2014) 'Townships as Crime "Hot-Spot" Areas in Cape Town: Perceived Root Causes of Crime in Site B, Khayelitsha', *Mediterranean Journal of Social Sciences*, 5(8), pp. 596–603. Available at: https://www.mcser.org/journal/index.php/mjss/article/view/2595 (Accessed: 14 November 2020).

Mays, N., Roberts, E. and Popay, J. (2001) 'Synthesising research evidence', in Fulop, N. et al. (eds) *Studying the organisation and delivery of health services: Research methods*. London: Routledge.

Mazorodze, B. T. (2020) 'Youth unemployment and murder crimes in KwaZulu-Natal, South Africa', *Cogent Economics & Finance*, 8(1), p. 1799480. Available at: https://doi.org/10.1080/23322039.2020.1799480 (Accessed: 14 November 2020).

Merlone, U., Manassero, E. and Zara, G. (2016) 'The Lingering Effects of Past Crimes over Future Criminal Careers', in Roeder, T. M. K. et al. (eds) *Proceedings of the 2016 Winter Simulation Conference (WSC)*. Washington, DC, pp. 3532–3543.

Merton, R. K. (1938) 'Social Structure and Anomie', *American Sociological Review*, 3(5), pp. 672–682.

Misra, A. K. (2014) 'Modeling the effect of police deterrence on the prevalence of crime in the society', *Applied Mathematics and Computation*, 237, pp. 531–545.

Mncube, V. and Madikizela-Madiya, N. (2014) 'Gangsterism as a cause of violence in South African schools: The case of six provinces', *Journal of Sociology and Social Anthropology*, 5(1), pp. 43–50. Available at: https://doi.org/10.1080/09766634.2014.11885608 (Accessed: 14 November 2020).

Morecroft, J. D. W. (2015) *Strategic modelling and business dynamics: A feedback systems approach*. Chichester, England: John Wiley & Sons.

Munyo, I. (2015) 'The juvenile crime dilemma', *Review of Economic Dynamics*, 18(2), pp. 201–211.

Nardin, L. G., Székely, Á. and Andrighetto, G. (2017) 'GLODERS-S : a simulator for agent-based models of criminal organisations', *Trends in organized crime*, 20(1), pp. 85–99.

National Planning Commission (2012a) *National Development Plan*. Available at: https://www.nationalplanningcommission.org.za/National_Development_Plan (Accessed: 18 October 2019).

National Planning Commission (2012b) 'National Development Plan 2030: Our future – make it work'. Pretoria, SA. Available at: http://www.dac.gov.za/sites/default/files/NDP 2030 - Our future - make it work_0.pdf (Accessed: 18 October 2019).

Nyabadza, F. and Coetzee, L. (2017) 'A Systems Dynamic Model for Drug Abuse and Drug-Related Crime in the Western Cape Province of South Africa', *Computational and Mathematical Methods in Medicine, 2017*, pp. 1–13.

Oliver, M. and Shapiro, T. (2006) *Black Wealth / White Wealth A New Perspective on Racial Inequality*. 2nd edn. New York: Routledge. Available at: https://doi.org/10.4324/9780203707425 (Accessed: 16 April 2020).

Ornstein, J. T. and Hammond, R. A. (2017) 'The Burglary Boost : A Note on Detecting Contagion Using the Knox Test', *Journal of Quantitative Criminology*, 33(1), pp. 65–75.

Osberg, L. (2017) 'On the Limitations of Some Current Usages of the Gini Index', *Review of Income and Wealth*, 63(3), pp. 574–584. Available at: http://search.ebscohost.com.ez.sun.ac.za/login.aspx?direct=true&db=buh&AN=124834180&site=ehost-live&scope=site (Accessed: 11 November 2020).

Pham, M. T. *et al.* (2014) 'A scoping review of scoping reviews: advancing the approach and enhancing the consistency', *Research synthesis methods*, 5(4), pp. 371–385. Available at: https://doi.org/10.1002/jrsm.1123 (Accessed: 16 November 2020).

Du Plessis, A. and Louw, A. (2005) 'Crime and Crime Prevention in South Africa: 10 Years After.', *Canadian Journal of Criminology & Criminal Justice*, 47(2), pp. 427–446.

Pruyt, E. (2013) *Small System Dynamics Models for Big Issues: Triple Jump towards Real-World Complexity*. First edi. Delft: TU Delft Library.

Quijada, S. E. *et al.* (2005) 'A Spatio Temporal Simulation Model for Evaluating Deliquency and Crime Policies', in *2005 Winter Simulation Conference*, pp. 1328–1334.

Redfern, J. *et al.* (2017) 'An open-data, agent-based model of alcohol related crime', in *2017 14th*

IEEE International Conference on Advanced Video and Signal Based Surveillance (AVSS). Lecce, pp. 1–6.

Rengifo, A. F. (2009) *Social Disorganization*, *Oxford Bibliographies Online*. Available at: https://doi.org/10.1093/OBO/9780195396607-000 (Accessed: 15 October 2019).

Republic of South Africa (1996) *South African Schools Act 84 of 1996*. Pretoria: Government Printer.

Republic of South Africa (1997) *Criminal Procedure Act 51 of 1977*. Available at: https://www.justice.gov.za/legislation/acts/1977-051.pdf (Accessed: 6 April 2020).

Richardson, G. and Pugh, A. L. (1997) 'Introduction to system dynamics modeling with DYNAMO', *Journal of the Operational Research Society*, 48(11), pp. 1146–1146.

Roberts, E. B. (1978) *Managerial applications of system dynamics*. Cambridge: MIT Press.

Robeyns, I. (2003) 'Sen's capability approach and gender inequality: Selecting relevant capabilities', *Feminist Economics*, 9(2–3), pp. 61–92.

Rosenfeld, R. and Messner, S. F. (1994) *Crime and the American Dream*. 1st edn. Belmont, California: Wadsworth.

Rosser, G. and Cheng, T. (2016) 'Improving the Robustness and Accuracy of Crime Prediction with the Self-Exciting Point Process Through Isotropic Triggering', *Applied Spatial Analysis and Policy*, 12(1), pp. 5–25.

Rufrancos, H. G. *et al.* (2013) 'Income Inequality and Crime: A Review and Explanation of the Time–series Evidence', *Sociology and Criminology*, 1(1), pp. 1–9. Available at: http://dx.doi.org/10.4172/2375-4435.1000103 (Accessed: 14 November 2020).

SAQA (2020) *What is the National Qualifications Framework (NQF)?* Available at: https://www.saqa.org.za/faq/what-national-qualifications-framework-nqf?language_content_entity=en (Accessed: 5 November 2020).

Sargent, R. G. (2013) 'Verification and validation of simulation models', *Journal of Simulation*, 7(1), pp. 12–24.

Saridakis, G. and Spengler, H. (2012) 'Crime, deterrence and unemployment in Greece: A panel data approach', *Social Science Journal*, 49(2), pp. 167–174.

Schmidt, J. W. and Taylor, R. E. (1970) *Simulation and Analysis of Industrial Systems*. Homewood, Illinois: Richard D. Irwin.

Schönteich, M. and Louw, A. (2011) *Crime in South Africa : A country and cities profile*. Occasional Paper No 49-2001, Crime and Justice Programme, Institute for Security Studies. Available at: https://www.africaportal.org/publications/crime-in-south-africa-a-country-and-cities-profile/ (Accessed: 16 March 2019).

Sen, A. (1973) *On Economic Inequality*. Oxford: Clarendon Press.

Senge, P. M. and Forrester, J. W. (1980) 'Tests for building confidence in system dynamics models', *System dynamics, TIMS studies in management sciences*, 14, pp. 209–228.

Shaw, C. R. and McKay, H. D. (1942) *Juvenile delinquency and urban areas*. University of Chicago Press.

Sickles, R. C. and Williams, J. (2008) 'Turning from crime: A dynamic perspective', *Journal of Econometrics*, 145(1–2), pp. 158–173.

South African Police Service (2009) *2007/2008 Annual Crime Report*. Available at:

https://www.saps.gov.za/about/stratframework/annualreports_arch.php (Accessed: 2 February 2019).

South African Police Service (2010) *2008/2009 Annual Crime Report*. Available at: https://www.saps.gov.za/about/stratframework/annualreports_arch.php (Accessed: 2 February 2019).

South African Police Service (2019) *2017/2018 Annual Crime Report*. Available at: https://www.saps.gov.za/services/annual_crime_report2019.pdf (Accessed: 4 February 2019).

Southern Africa Labour and Development Research Unit (2019) *What is NIDS?* Available at: http://www.nids.uct.ac.za/about/what-is-nids (Accessed: 18 November 2020).

Statistics South Africa (2008a) *Mid-year population estimates 2008: Statistical release*. Available at: http://www.statssa.gov.za/publications/P0302/P03022008.pdf (Accessed: 11 February 2019).

Statistics South Africa (2008b) *Quarterly Labour Force Survey 2008: Q1 [dataset]*. DataFirst. Available at: https://doi.org/10.25828/74t5-8b55 (Accessed: 20 June 2019).

Statistics South Africa (2009) *Quarterly Labour Force Survey 2009: Q1 [dataset]*. DataFirst. Available at: https://doi.org/10.25828/mfhb-2h05 (Accessed: 20 June 2019).

Statistics South Africa (2010) *Quarterly Labour Force Survey 2010: Q1 [dataset]*. DataFirst. Available at: https://doi.org/10.25828/6psd-v755 (Accessed: 20 June 2019).

Statistics South Africa (2011) *Quarterly Labour Force Survey 2011: Q1 [dataset]*. DataFirst. Available at: https://doi.org/10.25828/p7p1-e950 (Accessed: 20 June 2019).

Statistics South Africa (2012) *Quarterly Labour Force Survey 2012: Q1 [dataset]*. DataFirst. Available at: https://doi.org/10.25828/vw0h-fg73 (Accessed: 20 June 2019).

Statistics South Africa (2013a) *General Household Survey 2008 [dataset]*. DataFirst. Available at: https://doi.org/10.25828/129x-7w47 (Accessed: 16 April 2019).

Statistics South Africa (2013b) *General Household Survey 2009 [dataset]*. DataFirst. Available at: https://doi.org/10.25828/9vjw-ex06 (Accessed: 16 April 2019).

Statistics South Africa (2013c) *General Household Survey 2010 [dataset]*. DataFirst. Available at: https://doi.org/10.25828/qv5p-8s75 (Accessed: 16 April 2019).

Statistics South Africa (2013d) *General Household Survey 2011 [dataset]*. DataFirst. Available at: https://doi.org/10.25828/mv9d-0246 (Accessed: 16 April 2019).

Statistics South Africa (2013e) *General Household Survey 2012 [dataset]*. DataFirst. Available at: https://doi.org/10.25828/jpfy-2g79 (Accessed: 16 April 2019).

Statistics South Africa (2013f) *Quarterly Labour Force Survey 2013: Q1 [dataset]*. DataFirst. Available at: https://doi.org/10.25828/jyq9-ng05 (Accessed: 20 June 2019).

Statistics South Africa (2014a) *General Household Survey 2013 [dataset]*. DataFirst. Available at: https://doi.org/10.25828/a704-wm31 (Accessed: 16 April 2019).

Statistics South Africa (2014b) *Quarterly Labour Force Survey 2014: Q1 [dataset]*. DataFirst. Available at: https://doi.org/10.25828/4abt-7m54 (Accessed: 20 June 2019).

Statistics South Africa (2015) *Quarterly Labour Force Survey 2015: Q1 [dataset]*. DataFirst. Available at: https://doi.org/10.25828/zxnm-ns27 (Accessed: 20 June 2019).

Statistics South Africa (2016a) *General Household Survey 2015 [dataset]*. DataFirst. Available at: https://doi.org/10.25828/5b12-w270 (Accessed: 16 April 2019).

Statistics South Africa (2016b) *Quarterly Labour Force Survey 2016: Q1 [dataset]*. DataFirst. Available at: https://doi.org/10.25828/4hwj-cb40 (Accessed: 20 June 2019).

Statistics South Africa (2017a) *General Household Survey 2016 [dataset]*. DataFirst. Available at: https://doi.org/10.25828/ka3w-rg96 (Accessed: 16 April 2019).

Statistics South Africa (2017b) *Quarterly Labour Force Survey 2017: Q1 [dataset]*. DataFirst. Available at: https://doi.org/10.25828/zrtq-4638 (Accessed: 20 June 2019).

Statistics South Africa (2018a) *General Household Survey 2014 [dataset]*. DataFirst. Available at: https://doi.org/10.25828/nkvx-r352 (Accessed: 16 April 2019).

Statistics South Africa (2018b) *General Household Survey 2017 [dataset]*. DataFirst. Available at: https://doi.org/10.25828/6bvj-n342 (Accessed: 16 April 2019).

Statistics South Africa (2018c) *Mid-year population estimates 2018: Statistical release*. Available at: http://www.statssa.gov.za/publications/P0302/P03022018.pdf (Accessed: 11 February 2019).

Statistics South Africa (2018d) *Quarterly Labour Force Survey 2018: Q1 [dataset]*. DataFirst. Available at: https://doi.org/10.25828/mnwq-w661 (Accessed: 20 June 2019).

Statistics South Africa (2019) *General Household Survey 2018 [dataset]*. DataFirst. Available at: https://doi.org/10.25828/9tmn-fz97 (Accessed: 16 April 2019).

Sterman, J. (2000) *Business Dynamics: Systems thinking and modelling for a complex world*. 1st edn. New York, NY, USA: McGraw-Hill, Inc.

Sulla, V. and Zikhali, P. (2018) *Overcoming Poverty and Inequality in South Africa : An Assessment of Drivers, Constraints and Opportunities*. No 124521. Washington, DC. World Bank Group. Available at: http://documents.worldbank.org/curated/en/530481521735906534/Overcoming-Poverty-and-Inequality-in-South-Africa-An-Assessment-of-Drivers-Constraints-and-Opportunities (Accessed: 14 September 2018).

Sun, T. *et al.* (2010) 'The application of environmental Gini coefficient (EGC) in allocating wastewater discharge permit: The case study of watershed total mass control in Tianjin, China', *Resources, Conservation and Recycling*, 54(9), pp. 601–608.

SuperWEB2 (no date) *Online access to Statistics South Africa datasets*. Available at: http://superweb.statssa.gov.za/webapi (Accessed: 16 May 2019).

Sutherland, E. H. (1947) *Principles of criminology.* Chicago: J.B. Lippincott Co.

Tewksbury, R. (2014) 'Organized Crime Theories', *The Encyclopedia of Theoretical Criminology*. Chichester, UK: John Wiley & Sons, Ltd. Available at: http://doi.wiley.com/10.1002/9781118517390.wbetc166 (Accessed: 19 July 2018).

Thomas, V., Wang, Y. and Fan, X. (2001) *Measuring Education Inequality: Gini Coefficients of Education*. Policy Research Working Paper WPS2525. World Bank Institute. Available at: https://openknowledge.worldbank.org/bitstream/handle/10986/19738/multi_page.pdf?sequence=1 (Accessed: 2 October 2019).

UNESCO Institute for Statistics (2012) *Education : New entrants to primary education - South Africa (2012-2016)*. Available at: http://data.uis.unesco.org/# (Accessed: 21 February 2019).

UNESCO Institute for Statistics (2014) *Education: Effective transition rate from primary to secondary school in South Africa*. Available at: http://data.uis.unesco.org/# (Accessed: 21 February 2019).

Verma, A. and Lodha, S. K. (2002) 'A Topological Representation of the Criminal Event', *Western Criminology Review*, 3(2), pp. 37–48.

Verrinder, N. (2013) *Untangling the determinants of crime in South Africa*. Unpublished Doctoral dissertation. Cape Town: University of Cape Town. Available at: https://open.uct.ac.za/handle/11427/11547 (Accessed: 14 November 2020).

Weisburd, D. *et al.* (2017) 'Can Hot Spots Policing Reduce Crime in Urban Areas? an Agent-Based Simulation', *Criminology*, 55(1), pp. 137–173.

Wickes, R. and Sydes, M. (2017) *Social Disorganization Theory*, *Oxford Bibliographies Online*. Available at: https://www.oxfordbibliographies.com/view/document/obo-9780199756384/obo-9780199756384-0192.xml (Accessed: 15 October 2019).

Wikström, P.-O. H. (2009) *Routine Activity Theories*, *Oxford Bibliographies Online*. Available at: https://www.oxfordbibliographies.com/view/document/obo-9780195396607/obo-9780195396607-0010.xml (Accessed: 15 October 2019).

Wilhite, A. and Allen, W. D. (2008) 'Crime , protection , and incarceration', *Journal of Economic Behavior & Organization*, 67, pp. 481–494.

Winfree Jr., L. T. and Freng, A. (2015) 'Gangs and Social Learning Theory', in Decker, S. H. and Pyrooz, D. C. (eds) *The Handbook of Gangs*. Wiley (Wiley Online Books), pp. 118–135. Available at: https://doi.org/10.1002/9781118726822.ch7 (Accessed: 23 July 2018).

Winston, W. L. (2004) *Operations Research: Applications and Algorithms*. 4th edn. Belmont, Calif.: Wadsworth.

Wittek, R. (2017) *Rational Choice*, *Oxford Bibliographies Online*. Available at: https://www.oxfordbibliographies.com/view/document/obo-9780199756384/obo-9780199756384-0070.xml (Accessed: 15 October 2019).

Wolstenholme, E. F. (1992) 'The definition and application of a stepwise approach to model conceptualisation and analysis', *European Journal of Operational Research*, 59(1), pp. 123–136.

Woolard, I. and Klasen, S. (2004) *Determinants of Income Mobility and Household Poverty Dynamics in South Africa*. IZA Discussion Papers, No. 1030. Bonn: Institute for the Study of Labor (IZA).

World Bank (no date a) *GINI index (World Bank estimate)*, *World Development Indicators | DataBank*. Available at: https://databank.worldbank.org/reports.aspx?source=2&series=SI.POV.GINI&country=# (Accessed: 1 May 2020).

World Bank (no date b) *GINI index (World Bank estimate) - South Africa*, *World Development Indicators | DataBank*. Available at: https://data.worldbank.org/indicator/SI.POV.GINI?end=2014&locations=ZA&start=1993&view=chart (Accessed: 4 May 2020).

Wright, J. P. (2009) *Rational Choice Theories*, *Oxford Bibliographies Online*. Available at: https://www.oxfordbibliographies.com/view/document/obo-9780195396607/obo-9780195396607-0007.xml (Accessed: 15 October 2019).

Wright, V. (2010) *Deterrence in Criminal Justice: Evaluating Certainty vs. Severity of Punishment*. Washington, DC. The Sentencing Project. Available at: https://www.sentencingproject.org/wp-content/uploads/2016/01/Deterrence-in-Criminal-Justice.pdf (Accessed: 9 November 2019).

Van Wyk, C. (2015) 'An overview of key data sets in education in South Africa', *South African Journal of Childhood Education*, 5(2), pp. 146–170.

Yu, D. and Fang, C. (2017) 'The dynamics of public safety in cities: A case study of Shanghai from 2010 to 2025', *Habitat International*, 69, pp. 104–113.

Zoch, A. (2017) *The effect of neighbourhoods and school quality on education and labour market* *outcomes in South Africa*. Stellenbosch Economic Working Papers WP08/2017. Stellenbosch, South Africa: The Department of Economics and the Bureau for Economic Research, University of Stellenbosch. Available at: www.ekon.sun.ac.za/wpapers/2017/wp082017 (Accessed: 20 May 2019).

Appendices

9.1 Appendix A

Table 9.1: results from search string 1

Database	**Scopus**	**Science Direct**
Search string 1:	"system dynamics" AND "crime"	
Documents found	77	6
Accessible	7	3
Relevant to scope of study	2	2
Duplications	0	1

Table 9.2: results from search string 2

Database	**Scopus**	**Science Direct**
Search string 2:	"dynamic model" AND "crime"	
Documents found	95	14
Accessible	8	13
Relevant to scope of study	2	6
Duplications	0	0

Table 9.3: results from search string 3

Database	**Scopus**	**Science Direct**
Search string 3:	"simulation" AND "crime"	
Documents found	4319	89
Accessible	20	23
Relevant to scope of study	2	7
Duplications	1	1

Table 9.4: results from search string 4

Database	**Scopus**	**Science Direct**
Search string 4:	("agent-based model" OR "agent based model") AND "crime"	
Documents found	98	10
Accessible	10	10
Relevant to scope of study	7	3
Duplications	0	1

Table 9.5: references of sources used for the scoping review

Search terms	***Database***	**Author**	**Title**	**Reference**
'system dynamics' AND 'crime'	*Scopus*	Quijada, Sergio E; Arcas, Juan F; Renner, Cristian; Rabelo, Luis	A spatio temporal simulation model for evaluating delinquency and crime policies	(Quijada *et al.*, 2005)
		Sebastián, Jaén; Dyner, Isaac	Criminal cycles in the illegal drug industry: a system dynamics approach applied to Colombia	(Jaén & Dyner, 2008)
	ScienceDirect	Jaén, Sebastian; Dyner, Isaac	A system dynamics approach to the study of Colombian coca cultivation and the counter-intuitive consequence of law enforcement	(Jaén & Dyner, 2014)
		Danlin Yu , Chuanglin Fang	The dynamics of public safety in cities: A case study of Shanghai from 2010 to 2025	(Yu & Fang, 2017)
'dynamic model' AND 'crime'	*Scopus*	Lyndsay N. Boggess, John R. Hipp	The Spatial Dimensions of Gentrification and the Consequences for Neighborhood Crime	(Boggess & Hipp, 2016)
		Farai Nyabadza, Lezanie Coetzee	A Systems Dynamic Model for Drug Abuse and Drug-Related Crime in the Western Cape Province of South Africa	(Nyabadza & Coetzee, 2017)
	ScienceDirect	George Saridakis, Hannes Spengler	Crime, deterrence and unemployment in Greece: A panel data approach	(Saridakis & Spengler, 2012)
		Antoni Calvó-Armengol, Thierry Verdier, Yves Zenou	Strong and weak ties in employment and crime	(Calvó-Armengol, Verdier & Zenou, 2007)
		Ignacio Munyo	The juvenile crime dilemma	(Munyo, 2015)
		Robin C. Sickles, Jenny Williams	Turning from crime: A dynamic perspective	(Sickles & Williams, 2008)
		Pablo Fajnzylber, Daniel Lederman, Norman Loayza	What causes violent crime?	(Fajnzylber, Lederman & Loayza, 2002b)

		S. J. Deutsch, C. J. Malmborg	A dynamic model to forecast incapacitation and deterrence effects	(Deutsch & Malmborg, 1985)
'simulation' AND 'crime'	*Scopus*	Timothy C. Haas, Sam M. Ferreira	Combating Rhino Horn Trafficking: The Need to Disrupt Criminal Networks	(Haas & Ferreira, 2016)
		Gabriel Rosser, Tao Cheng	Improving the Robustness and Accuracy of Crime Prediction with the Self-Exciting Point Process Through Isotropic Triggering	(Rosser & Cheng, 2016)
	ScienceDirect	Vasco Furtado, Adriano Melo, André L.V. Coelho, Ronaldo Menezes, Ricardo Perrone	A bio-inspired crime simulation model	(Furtado *et al.*, 2009)
		Nick Malleson, Mark Birkin	Analysis of crime patterns through the integration of an agent-based model and a population microsimulation	(Malleson & Birkin, 2012)
		John R. Hipp, Carter T. Butts, Ryan Acton, Nicholas N. Nagle, Adam Boessen	Extrapolative simulation of neighborhood networks based on population spatial distribution: Do they predict crime?	(Hipp *et al.*, 2013)
		Nelson Devia, Richard Weber	Generating crime data using agent-based simulation	(Devia & Weber, 2013)
		A.K. Misra	Modeling the effect of police deterrence on the prevalence of crime in the society	(Misra, 2014)
		Yoonseok Hwang, Sungwon Jung, Jaewook Lee, Yongwook Jeong	Predicting residential burglaries based on building elements and offender behavior: Study of a row house area in Seoul, Korea	(Hwang *et al.*, 2017)
		Caterina Astarita, Carlo Capuano, Francesco Purificato	The macroeconomic impact of organised crime: A post-Keynesian analysis	(Astarita, Capuano & Puri, 2018)
'agent based model' AND 'crime'	*Scopus*	Daniel Birks, Toby Davies	Street network structure and crime risk: an agent-based investigation of the encounter and enclosure hypotheses	(Birks & Davies, 2017)

		Corinna Elsenbroich	The Addio Pizzo movement: exploring social change using agent-based modelling	(Elsenbroich, 2017)
		Ugo Merlone, Eugenio Manassero, Georgia Zara	The lingering effects of past crimes over future criminal careers	(Merlone, Manassero & Zara, 2016)
		Luis Gustavo Nardin, Áron Székely, Giulia Andrighetto	GLODERS-S: a simulator for agent-based models of criminal organisations	(Nardin, Székely & Andrighetto, 2017)
		Joseph T. Ornstein, Ross A. Hammond	The Burglary Boost: A Note on Detecting Contagion Using the Knox Test	(Ornstein & Hammond, 2017)
		Joseph Redfern, Kirill Sidorov, Paul L. Rosin, Simon C. Moore, Padraig Corcoran, David Marshall	An Open-data, Agent-based Model of Alcohol Related Crime	(Redfern *et al.*, 2017)
		David Weisburd, Anthony A. Braga, Elizabeth R. Groff, Alese Wooditch	Can hot spots policing reduce crime in urban areas? An agent-based simulation	(Weisburd *et al.*, 2017)
	ScienceDirect	Allen Wilhite, W. David Allen	Crime, protection, and incarceration	(Wilhite & Allen, 2008)
		Nick Malleson, Alison Heppenstall, Linda See	Crime reduction through simulation: An agent-based model of burglary	(Malleson, Heppenstall & See, 2010)
		Huanfa Chen, Tao Cheng, Sarah Wise	Developing an online cooperative police patrol routing strategy	(Chen, Cheng & Wise, 2017)

9.2 Appendix B

Appendix B contains derivations of reference modes, as well as estimations of constants used for the simulation model.

9.2.1 Appendix B1

Appendix B1 discussed the derivation of reference modes for the five highest- and final education levels of the education sub-model.

Estimations were based on the raw numbers obtained through the Quarterly Labour Force Surveys (QLFS) of the first quarters between 2008 and 2018 (Statistics South Africa, 2008b, 2009, 2018d, 2010, 2011, 2012, 2013f, 2014b, 2015, 2016b, 2017b). Two responses[48] from the surveys were merged using the online tool "SuperWEB2" for accessing datasets from Statistics South Africa (SuperWEB2, no date). The first response specifies an individual's age. The second response specifies an individual's education status, which corresponds to the individual's highest level of education. The second response was grouped into seven categories as may be seen in Figure 9.1. Only categories two to six were used for the reference modes of the model. The "other" category is not clearly defined and only amounts to an estimated 0.8 % of the population. Therefore, it was excluded from the model.

Dataset: Quarterly Labour Force Survey 2008 (Q1 revised)

Variable Education_Status: Education Status

Values	Categories	N	NW	
1	No schooling	20304	9,829,045.7	19.9%
2	Less than primary completed	22399	10,956,533.9	22.2%
3	Primary completed	6017	2,916,359.7	5.9%
4	Secondary not completed	28012	14,509,872.9	29.4%
5	Secondary completed	12815	7,590,027.0	15.4%
6	Tertiary	4954	3,139,594.6	6.4%
7	Other	685	373,888.9	0.8%

Figure 9.1: Broad education categories, of the 2008 QLFS (Q1), used for estimation of South African education trends

Figure 9.2 shows the raw numbers for merging the responses for education status with the responses for age of individuals. The trends for 2012, as seen in Figure 9.2, are very similar to the trends of other years of the QLFS. From Figure 9.2 it can be seen that responses for primary school only start at age six and that responses for "no schooling" are predominantly for those of age five and younger. Figure 9.2 is an indication that very few South Africans do not undergo any education throughout their lifetime. Therefore, it was assumed that all South Africans undergo some form of education through their lifetime. For this reason, the "no schooling" category was excluded from the model.

From Figure 9.2, it can be seen that responses for the "less than primary completed" (LTPC) category only start at age six and strongly decrease at about age fifteen. This is an indication that most South Africans between the ages of six and fifteen are attending primary school. The *LTPC out of school* stock from the education sub-model is aimed at representing the population of South Africans that are not attending any educational institution and have obtained grade one to six as their highest- and final level of education. Figure 9.2 shows that there is a proportion of South Africans that seems to fit this category from about age sixteen until an old age. Therefore, the reference mode for the *LTPC out of school* stock estimated as consisting of individuals who are sixteen years and older and have an education status of "less than primary completed".

[48] A response refers to the answer an individual provides for a specific question of the survey.

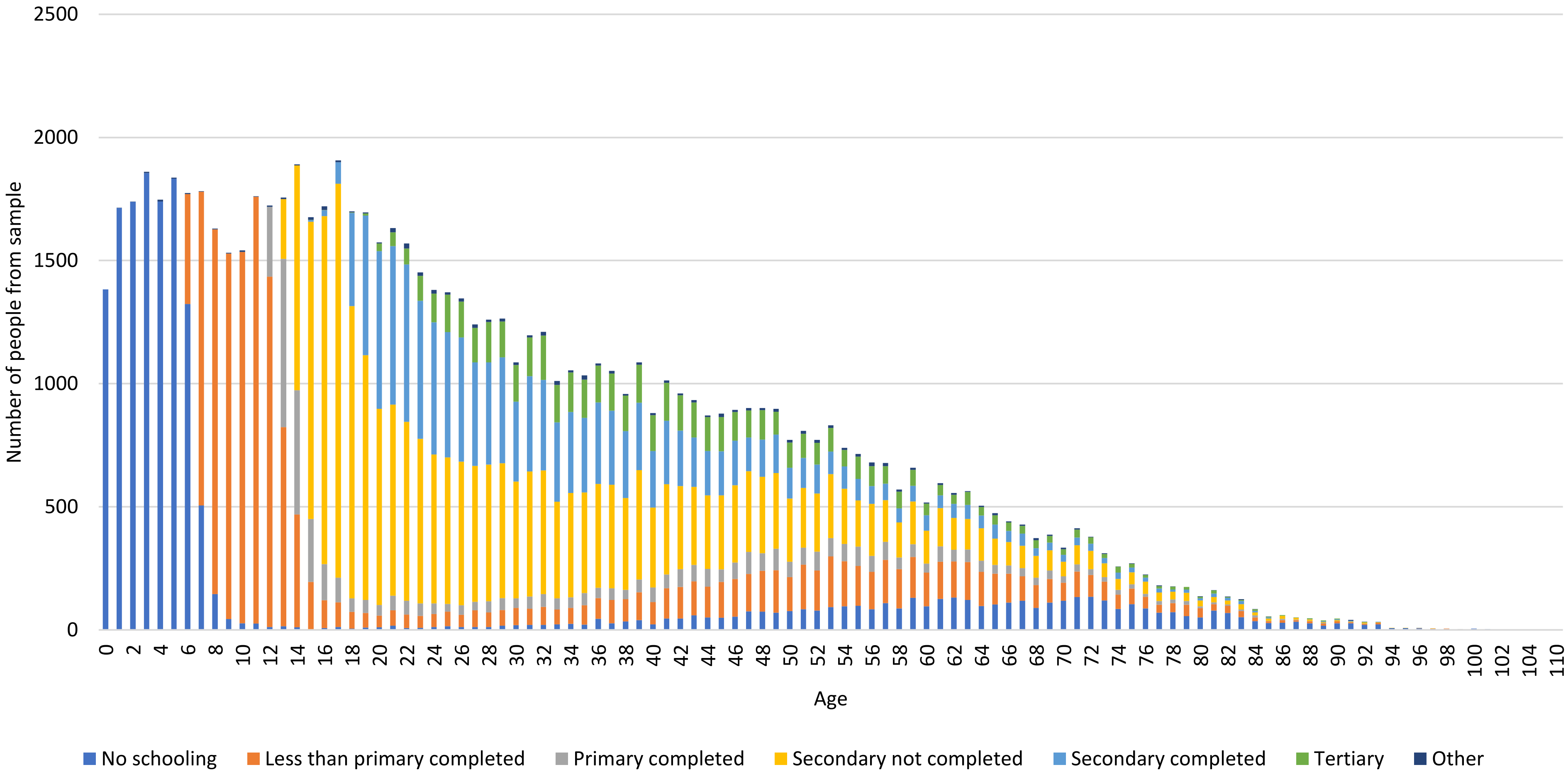

Figure 9.2: Education status according to age extracted from the first quarter of the 2012 QLFS through SuperWEB2

A similar approach was used to estimate the reference modes for the other final- and highest education level stocks of the model, but with different age ranges. Table 9.6 shows the age ranges used to estimate the reference modes for the five highest- and final education level population stocks of the education sub-model.

Table 9.6: Age ranges used to estimate reference modes for the five final-and highest education level population stocks of the education sub-model

Education status	Age range
Less than primary completed	16 years and older
Primary completed	16 years and older
Secondary not completed	21 years and older
Secondary completed	23 years and older
Tertiary	23 years and older

The raw numbers from the samples were used to create values that represent the percentage of the South African population that falls into each of the five education levels of interest for each respective year. These percentages were then multiplied with the total South African population size obtained from the General Household Survey of each respective year. This then produced the trends, shown in Figure 5.2, that serve as reference modes for the education sub-model.

9.2.2 Appendix B2

Appendix B2 describes the derivation of five household income level population stocks of the income sub-model.

The estimations for the five household income level population stocks are based on data obtained from the General Household Surveys conducted between 2009 and 2018 (Statistics South Africa, 2013b, 2013c, 2013d, 2013e, 2014a, 2016a, 2017a, 2018a, 2018b, 2019). For these datasets, again two responses[49] were merged. The first response refers to the highest level of education that the responding individual has achieved. The second response refers to the average monthly income of the household that the individual lives in. For the estimation of the income levels, five monthly household income categories were created. The result of this derivation for the data obtained through the 2009 General Household Survey may be seen in Figure 9.3. The education levels of Figure 9.3 correspond to the ones shown in Table 9.6 and were abbreviated for the sake of brevity. The numbers shown in Figure 9.3 do not account for the entire South African population, but only for those with the mentioned education levels. Therefore, the population with education levels such as no schooling and master's degrees were not accounted for. The method used to generate the numbers used for Figure 9.3 was applied to the General Household Surveys conducted between 2009 and 2018. This allowed to create the trends shown in Figure 5.3. These trends were used as reference modes for the five income category populations of the income sub-model.

[49] A response refers to the answer an individual provides for a specific question of the survey.

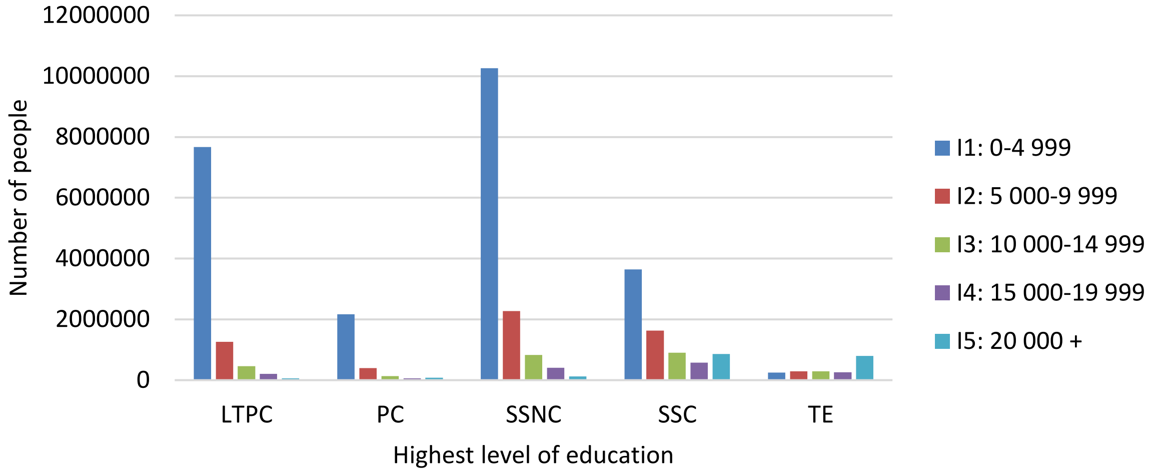

Figure 9.3: Result for derivation of income categories for data obtained through the 2009 General Household Survey

9.2.3 Appendix B3

Appendix B3 describes the derivation of the ratios that are used to influence the five progression flows of the income sub-model.

The ratios for the five progression flows of the income sub-model were derived from the trends shown in Figure 5.3. Firstly, values were calculated that represent the percentage of the population within a specific income category that has achieved a particular education level. This was done for all education levels and all income categories. This was repeated for every year that the income trends represent. An example for the derivation of percentages for 2009 may be seen in Table 9.7. Then the averages for 2009 to 2018 were calculated the results may be seen in Table 9.8. These ratios were used to control the progression flows of the income sub-model.

Table 9.7: Derivation of ratios for 2009 of income sub-model progression flows

2009	LTPC	PC	SSNC	SSC	TE
I1: R0 - R4,999	0.79377	0.762589	0.73844	0.478372	0.132474
I2: R5,000 – R9,999	0.130573	0.139996	0.16368	0.214139	0.152388
I3: R10,000 – R14,999	0.047475	0.046684	0.059811	0.117965	0.156187
I4: R15,000 – R19,999	0.021677	0.022273	0.029305	0.076201	0.135599
I5: R20,000 +	0.006505	0.028458	0.008764	0.113323	0.423353
Totals	1	1	1	1	1

Table 9.8: Averages of ratios calculated for 2009-2018 income category trends

Average	LTPC	PC	SSNC	SSC	TE
I1: R0 - R4,999	0.685631	0.690911	0.646071	0.429029	0.122322
I2: R5,000 – R9,999	0.162656	0.171453	0.188714	0.214272	0.120222
I3: R10,000 – R14,999	0.056859	0.056867	0.069709	0.112746	0.127437
I4: R15,000 – R19,999	0.026999	0.026941	0.031838	0.064728	0.096434
I5: R20,000 +	0.067855	0.053829	0.063667	0.179225	0.533585
Totals	1	1	1	1	1

9.2.4 Appendix B4

Appendix B4 describes the derivation of the constants named *i%* to *v%* of the structure that represents the influence of the income category populations of the income sub-model on the tertiary education access rates of the education sub-model.

The ratios for variables *i%* to *v%* were based on data from 2009 General Household Survey. Again, two responses from the survey were merged to obtain the data necessary for this derivation. The first response specifies that the individual interviewed is currently in grade 12. The second response refers to the individual's household income. The pupils were grouped into five income categories as shown in Table 9.9.

Table 9.9: Number of grade 12 pupils living in households of specified income ranges according to data obtained from the GHS of 2009

Income category	Number of pupils in grade 12
I1: R0 - R4,999	518,553
I2: R5,000 – R9,999	117,452
I3: R10,000 – R14,999	50,146
I4: R15,000 – R19,999	44,117
I5: R20,000 +	67,110

To derive the values for *i%* to *v%*, the number of grade 12 pupils per income category shown in Table 9.9 were divided by the number of people in that income category in 2009, which was derived to create the trends of Figure 5.3. The results may be seen in Table 9.10. The numbers in Table 9.10 were used as a starting point for the model, but were altered slightly during the calibration of the model. The altered estimations of the constants may be found in Appendix C3.

Table 9.10: Result from derivation used to estimate constants i%-v%

Name of constant	Result from derivation
i%	0.021615723036
ii%	0.020069181184
iii%	0.019171503091
iv%	0.029098274877
v%	0.034826711090

9.2.5 Appendix B5

Appendix B5 describes the derivation of the constants that form part of the variables named *ia%* to *va%* of the structure that represents the influence of the income category populations of the income sub-model on the tertiary education access rates of the education sub-model. This derivation builds on some of the information mentioned in Appendix B4.

South African public ordinary schools are categorised into five groups, called quintiles, largely for purposes of the allocation of governmental finances. Quintile 1 (Q1) is the group of schools in each province catering for the poorest 20% of learners. Quintile 2 (Q2) schools cater for the next poorest 20% of schools and so on. Therefore, quintile 5 (Q5) schools are those schools that cater for the least poor 20% of learners in the country. In a study investigating higher education access of the 2008 National Senior Certificate (NSC) cohort, van Broekhuizen, van der Berg and Hofmeyr (2018) have estimated the six-year undergraduate access rates among the cohort. Some of the results may be seen in Table 9.11. Due to the argument relating to Table 4.2 in sub-section 4.1.3, it was assumed that the five schooling quintiles may be related to five household income quintiles. Therefore, the number of grade 12 pupils per household income quintile was calculated using the number of grade 12 pupils as shown by Table 9.9 of the previous section. The results may be seen in Table 9.12.

Table 9.11: Estimated six-year undergraduate access rates (%) among the 2008 cohort, by school quintile for undergraduate studies (Amended from van Broekhuizen, van der Berg & Hofmeyr, 2018: p.93)

School quintile	Six-year undergraduate access rates (%) among the 2008 cohort, by school quintile for undergraduate studies
1	9.2
2	11.2
3	14.7
4	23.5
5	45.2

Table 9.12: Estimated number of grade 12 pupils in respective household income quintile in 2009

Household income quintile	Estimated number of grade 12 pupils in respective household income quintile
1	157,582
2	159,233
3	158,855
4	160,335
5	161,374

To adjust the results of Table 9.11 from the five school quintiles to the five income categories of the income sub-model, it was calculated how many pupils of each schooling quintile fall under each of the five income categories. The six-year undergraduate access rates from Table 9.11 were then adjusted accordingly. The results of this may be seen in Table 9.13. The values of the constants shown in Table 9.13 were adjusted slightly during the calibration process. The equations for the five variables listed in Table 9.13, with their adjusted constants, may be found in Appendix C3.

Table 9.13: Estimated six-year undergraduate access rates (%) among the 2008 cohort, by household income category for undergraduate studies

Variable that constant is associated with	Variable description	Constant value
ia%	This variable represents the percentage of grade 12 learners, living in households with an average monthly income of less than *R* 5,000, that access tertiary education within six years of completing matric.	12.68
iia%	This variable represents the percentage of grade 12 learners, living in households with an average monthly income between *R* 5,000 and *R* 9,999, that access tertiary education within six years of completing matric.	23.50
iiia%	This variable represents the percentage of grade 12 learners, living in households with an average monthly	45.20

	income between *R* 10,000 and *R* 14,999, that access tertiary education within six years of completing matric.	
iva%	This variable represents the percentage of grade 12 learners, living in households with an average monthly income between *R* 10,000 and *R* 14,999, that access tertiary education within six years of completing matric.	45.20
va%	This variable represents the percentage of grade 12 learners, living in households with an average monthly income of more than *R* 20,000, that access tertiary education within six years of completing matric.	45.20

9.3 Appendix C

Appendix C contains tables and figures for all variables used to create the system dynamics model structure.

9.3.1 Appendix C1

Appendix C1 contains tables and figures for all variables used to create the education sub-model.

Table 9.14 provides an overview of the stocks used for the education sub-model regarding the formulation of equations and specification of units. All stocks were specified as variables of type "Level" and sub-type "Normal". Table 9.14 contains the equations of the stocks as they are specified in the equation editor. All initial conditions specified for the stocks of the education sub-model are described in Table 9.15. Variables acting as initial conditions were declared as type "Constant" with sub-type "Normal". Table 9.16 lists the equations and units for all flows of the education sub-model. Flow variables are declared as "Auxiliary" type and "Normal" sub-type. Equations of flows are presented as specified in the equation editor window. Table 9.17 lists the auxiliary variables of the education sub-model. The auxiliary variables are declared as type "Auxiliary" and sub-type "Normal". Table 9.18 lists and describes the constants used for the education sub-model. All constants were declared as type "Constant" and sub-type "Normal".

Table 9.14: Specification of stocks developed for education sub-model

Stock name	Stock equation	Units	Description
Primary school population	grade 1 enrolments-LTPC dropouts-PC dropouts-SS enrolments	People	Population size of South Africans attending primary school.
Secondary school population	SS enrolments-exiting SS for further studies-matriculants-SSNC dropouts	People	Population size of South Africans attending secondary school.
Undergraduate Diploma and Bachelor headcount	(delayed enrolment of SSC out of school)+exiting SS for further studies-graduates-TE dropouts	People	Population size of South Africans enrolled at tertiary education institutions for undergraduate degrees and diplomas of NQF levels 6, 7 and 8.
LTPC out of school	LTPC dropouts-deaths of LTPC	People	Population size of South Africans formerly enrolled in primary school, but did not obtain grade 7. Their highest- and final level of education is regarded as "less than primary school completed".
PC out of school	PC dropouts-deaths of PC	People	Population size of South Africans that completed primary school (grade 7) without continuing with any further education. Their highest- and final level of education is therefore regarded as "primary school completed".
SSNC out of school	SSNC dropouts-deaths of SSNC-SSNC going for AET-SSNC going for FET	People	Population size of South Africans formerly enrolled in secondary school, but did not obtain the NSC (grade 12). Their highest- and final level of education is regarded as "secondary school not completed".
SSC out of school	matriculants-deaths of SSC-delayed enrolment of SSC out of school-SSC	People	Population size of South Africans that obtained the NSC (grade 12) without continuing with any further education.

	going for AET-SSC going for FET		Their highest- and final level of education is therefore regarded as "secondary school completed".
Tertiary education completed	graduates-deaths of TEC	People	Population size of South Africans that obtained undergraduate degrees and diplomas equivalent to NQF levels 6, 7 and 8. Their highest- and final level of education is therefore regarded as “tertiary education completed”.
SA Population	SA births-SA deaths	People	South African population

Table 9.15: Specification of initial values for stocks of the education sub-model

Initial value name	Quantity	Unit	Description
initial primary school population	7.23166e+06	People	Number of pupils enrolled in South African primary schools in 2008 (Department for Basic Education South Africa, 2008)
initial secondary school population	4.40375e+06	People	Number of pupils enrolled in South African secondary schools in 2008 (Department for Basic Education South Africa, 2008)
initial undergraduate population	417330	People	Headcount of students enrolled for undergraduate degrees and diplomas of NQF levels 6, 7 and 8 in 2008 (IDSC, no date)
initial LTPC out of school population	4.51442e+06	People	Estimated population size, in 2008, of people formerly enrolled in primary school, but did not obtain grade 7. Their highest- and final level of education is regarded as "less than primary school completed". Estimates were generated from data of the GHS and QLFS(Q1) of 2008 (Statistics South Africa, 2008b, 2013a).
initial PC out of school population	2.10739e+06	People	Estimated population size, in 2008, of people that completed primary school (grade 7) without continuing with any further education. Their highest- and final level of education is therefore regarded as "primary school completed". Estimates were generated from data of the GHS and QLFS(Q1) of 2008 (Statistics South Africa, 2008b, 2013a).
initial SSNC out of school population	8.87666e+06	People	Estimated population size, in 2008, of people formerly enrolled in secondary school, but did not obtain the NSC (grade 12). Their highest- and final level of education is regarded as "secondary school not completed". Estimates were generated from data of the GHS and QLFS(Q1) of 2008 (Statistics South Africa, 2008b, 2013a).
initial SSC out of school population	4.83912e+06	People	Estimated population size, in 2008, of people that obtained the NSC (grade 12) without continuing with any further education. Their highest- and final level of education is therefore regarded as "secondary school completed". Estimates were

			generated from data of the GHS and QLFS(Q1) of 2008 (Statistics South Africa, 2008b, 2013a).
initial TEC population	1.70405e+06	People	Estimated population size, in 2008, of people that obtained undergraduate degrees and diplomas equivalent to NQF levels 6, 7 and 8. Their highest- and final level of education is therefore regarded as "tertiary education completed". Estimates were generated from data of the 2008 GHS (Statistics South Africa, 2013a).
initial SA population	4.86873e+07	People	South African population size in 2008 (Statistics South Africa, 2008b: p.13)

Table 9.16: Specification of flows developed for the education sub-model

Flow name	Flow equation	Unit
grade 1 enrolments	SA Population*(% of population entering Grade 1)	People /Year
LTPC dropouts	Primary school population*LTPC dropout rate	People /Year
PC dropouts	Primary school population*grade 7 ratio*PC dropout rate	People /Year
SS enrolments	Primary school population*grade 7 ratio*effective transition rate	People /Year
SSNC dropouts	Secondary school population*SS dropout rate	People /Year
SSNC going for AET	SSNC out of school*SSNC AET enrolment rate	People /Year
SSNC going for FET	SSNC out of school*SSNC FET enrolment rate	People /Year
deaths of SSNC	(SSNC out of school*SA crude death rate)/1000	People /Year
matriculants	Secondary school population*grade 12 ratio*SSC exit rate	People /Year
SSC going for AET	SSC out of school*SSC AET enrolment rate	People /Year
SSC going for FET	SSC out of school*SSC FET enrolment rate	People /Year
deaths of SSC	(SSC out of school*SA crude death rate)/1000	People /Year
exiting SS for further studies	immediate enrolments	People /Year
delayed enrolment of SSC out of school	delayed enrolments	People /Year
TE dropouts	Undergraduate Diploma and Bachelor headcount*TE dropout rate	People /Year
graduates	Undergraduate Diploma and Bachelor headcount*graduation rate	People /Year
deaths of TEC	(Tertiary education completed*SA crude death rate)/1000	People /Year
SA births	(SA crude birth rate*SA Population)/1000	People /Year
SA deaths	(SA crude death rate*SA Population)/1000	People /Year

Table 9.17: Specification auxiliary variables created for the education sub-model

Variable name	Variable equation	Unit	Description
LTPC dropout rate	Normal LTPC dropout rate*LTPC dropout rate TABLE(Time/Dropout rate reference year)	Dimensionless/ Year	This rate was originally a constant. Intermediate testing revealed that a constant rate brings about unrealistic results when running the model up to the year 2400. It was therefore assumed that the dropout rate at primary school decreased by 20 % every 50 years until 2250. More details about this may be found under the discussion of the lookup functions for this sub-model.
PC dropout rate	Normal PC dropout rate*PC dropout rate TABLE(Time/Dropout rate reference year)	Dimensionless/ Year	The PC dropout rate has been defined in a similar manner as the LTPC dropout rate and for the same reason.

Table 9.18: Specification constants created for the education sub-model

Constant name	Value	Unit	Description
% of population entering Grade 1	0.0179203	Dimensionless/ Year	Estimate percentage of the entire South African population that enrols for grade 1 annually. Constant was estimated from data obtained from the UNESCO Institute for Statistics (2012). Constant was originally estimated at 0.0243902. Through calibration, the value was reduced within a reasonable range.
Dropout rate reference year	2008	Year	The *dropout rate reference year* is used to normalise the *Time* variable to produce a dimensionless input for the *LTPC dropout rate TABLE* lookup function.
Normal LTPC dropout rate	0.00008	Dimensionless/ Year	This constant represents a fraction of the primary school population that drops out of school annually, before completing grade 7. The value was not obtainable from literature and historical data. Therefore, the constant was estimated through calibration. The calibrated value allowed the simulation results to fit the real world data (reference modes) obtained for the stocks of the model.
grade 7 ratio	0.12815	Dimensionless	The *grade 7 ratio* represents the fraction of the primary school population that is enrolled in grade 7. The ratio was estimated by calculating the 2009-2017 average grade 7 population as a percentage of the total primary school population using the data published in School Realities (Department for Basic Education South Africa, 2009, 2010, 2011, 2013, 2014, 2015, 2016, 2017).

Normal PC dropout rate	0.00085	Dimensionless/ Year	This constant represents a fraction of the primary school population that discontinues any further education after completing grade 7. The value was not obtainable from literature and historical data. Therefore, the constant was estimated through calibration. The calibrated value allowed the simulation results to fit the real world data (reference modes) obtained for the stocks of the model.
effective transition rate	0.98	Dimensionless/ Year	The *effective transition rate* represents the fraction of the pupils enrolled in grade 7 that will enrol for secondary school the following year, annually. Note that the *Normal PC dropout rate* and the *effective transition rate* do not add up to one. This is considered to be due to several grade 7 learners repeating the grade each year. The value was originally estimated at 0.973 from the data provided by the UNESCO Institute for Statistics (2014). The value was then adjusted slightly during model calibration.
SS dropout rate	0.0844671	Dimensionless/ Year	The secondary school dropout rate acts as the fraction of secondary school learners that drops out of secondary school before attaining the NSC (completing grade 12), annually. The value was not obtainable from literature and historical data. Therefore, the constant was estimated through calibration. The calibrated value allowed the simulation results to fit the real world data (reference modes) obtained for the stocks of the model.
SSNC AET enrolment rate	0.00180465	Dimensionless/ Year	This ratio represents the fraction of the *SSNC out of school* population stock that annually enrols at AET centres. This value could not be obtained from available literature and data. Therefore, the value was estimated with the built-in calibration tool by fitting the simulation results to the reference modes for the stocks through the adjustment of the constant.
SSNC FET enrolment rate	0.00450662	Dimensionless/ Year	This ratio represents the fraction of the *SSNC out of school* population stock that annually enrols at FET centres. This value could not be obtained from available literature and data. Therefore, the value was estimated with the built-in calibration tool by fitting the simulation results to the reference modes for the stocks through the adjustment of the constant.
SSC exit rate	0.741669	Dimensionless/ Year	This ratio represents the fraction of grade 12 leaners, of any year, that pass grade 12 and do not immediately progress to tertiary education. The ratio was estimated from results produced by Branson, Hofmeyr and

			Lam (2014: p.112) and then adjusted slightly during calibration.
grade 12 ratio	0.134246	Dimensionless	This ratio represents the fraction of the secondary school population that is enrolled in grade 12. The ratio was estimated by calculating the 2009-2017 average grade 12 population as a percentage of the total primary school population using the data published in School Realities (Department for Basic Education South Africa, 2009, 2010, 2011, 2013, 2014, 2015, 2016, 2017).
SSC AET enrolment rate	0.0001	Dimensionless/ Year	This ratio represents the fraction of the *SSC out of school* population stock that annually enrols at AET centres. This value could not be obtained from available literature and data. Therefore, the value was estimated with the built-in calibration tool by fitting the simulation results to the reference modes for the stocks through the adjustment of the constant.
SSC FET enrolment rate	0.0109196	Dimensionless/ Year	This ratio represents the fraction of the *SSC out of school* population stock that annually enrols at FET centres. This value could not be obtained from available literature and data. Therefore, the value was estimated with the built-in calibration tool by fitting the simulation results to the reference modes for the stocks through the adjustment of the constant.
TE dropout rate	0.03	Dimensionless/ Year	The *TE* (Tertiary Education) *dropout rate* represents the fraction of the *Undergraduate Diploma and Bachelor headcount* stock that annually drops out of their respective course. This value could not be obtained from available literature and data. Therefore, the value was estimated with the built-in calibration tool by fitting the simulation results to the reference modes for the stocks through the adjustment of the constant.
graduation rate	0.122802	Dimensionless/ Year	This constant represents the fraction of the *Undergraduate Diploma and Bachelor headcount* stock that annually graduates from their respective course. This value could not be obtained from available literature and data. Therefore, the value was estimated with the built-in calibration tool by fitting the simulation results to the reference modes for the stocks through the adjustment of the constant.
SA crude birth rate	29.7702	Dimensionless/ Year	The *SA crude birth rate* represents the number of live births occurring among the South African population during 2008, per 1000 mid-year total population during the same year. The value was obtained from the Mid-year population estimates of South Africa by Statistics South Africa (2018c: p.21).

SA crude death rate	12.9077	Dimensionless/ Year	The *SA crude death rate* represents the number of deaths occurring among the South African population during 2008, per 1000 mid-year total population during the same year. The value was obtained from the Mid-year population estimates of South Africa by Statistics South Africa (2018c: p.21).

The variable *LTPC dropout rate TABLE* was declared as a lookup function as shown in Figure 9.4. This variable is implemented to represent a steady reduction of the *Normal LTPC dropout rate*. This is due to the fact that the simulation model generates unrealistic results for the *LTPC out of school* stock if the *Normal LTPC dropout rate* stays constant throughout a simulation that runs up to the year 2400. With this implementation it is therefore assumed that a 20 % reduction in *Normal LTPC dropout rate* occurs every 50 years up to the year 2250. The same approach was used for the *Normal PC dropout rate* for the same reason as for the *Normal LTPC dropout rate*. The lookup function for *PC dropout rate TABLE* is shown in Figure 9.5.

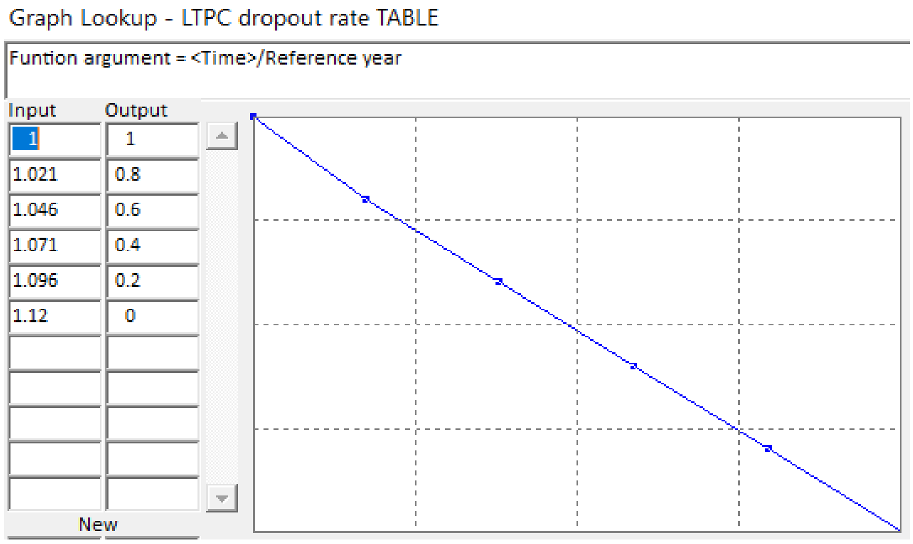

Figure 9.4: Lookup function specified for LTPC dropout rate TABLE

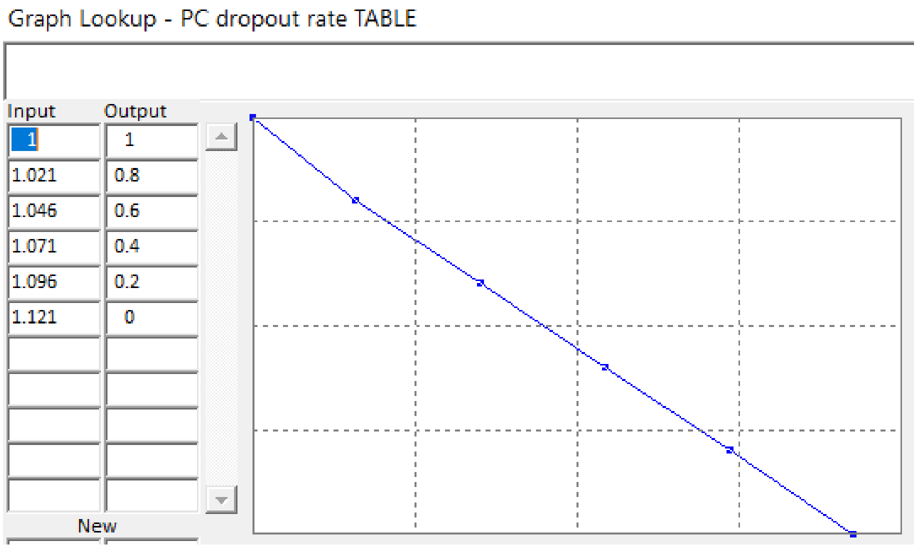

Figure 9.5: Lookup function specified for PC dropout rate TABLE

9.3.2 Appendix C2

Appendix C2 contains descriptions for all variables used to create the income sub-model.

Table 9.19 provides an overview of the stocks used for the income sub-model regarding the formulation of equations and specification of units. All stocks were specified as variables of type “Level” and sub-type “Normal”. Table 9.19 contains the equations of the stocks as they are specified in the equation editor. All initial conditions specified for the stocks of the income sub-model are described in Table 9.20. Variables acting as initial conditions were declared as type “Constant” with sub-type “Normal”. Table 9.21 lists the equations and units for all flows of the income sub-model. Flow variables are declared as “Auxiliary” type and “Normal” sub-type. Equations of flows are presented as specified in the equation editor window. Table 9.22 lists and describes the constants used for the income sub-model. All constants were declared as type “Constant” and sub-type “Normal”. Constants *LTPC I1 %* to *TEC I5 %*, required for creating the progression inflows of the income category stocks, were derived from data obtained from the General Household Surveys from 2008 up to 2018 (Statistics South Africa, 2013a, 2013c, 2019, 2013d, 2013e, 2013b, 2014a, 2016a, 2017a, 2018a, 2018b). A visual representation of this may be seen in Figure 4.6 of Chapter 4. The upward- and downward mobility rates were derived through calibration by adjusting the constants, so that the simulation results fit the real world data of the income population stocks.

Table 9.19: Specification of stocks developed for income sub-model

Stock name	Stock equation	Units	Description
I1	I1 progressions+I2 downward mobility-I1 deaths-I1 upward mobility	People	*I1* represents a population of South Africans that are not attending any educational institution. People in this population have reached their highest- and final level of education. The range of average monthly household income for this population is between *R* 0 and *R* 4,999.
I2	I1 upward mobility+I2 progressions+I3 downward mobility-I2 deaths-I2 downward mobility-I2 upward mobility	People	*I2* represents a population of South Africans that are not attending any educational institution. People in this population have reached their highest- and final level of education. The range of average monthly household income for this population is between *R* 5,000 and *R* 9,999.
I3	I2 upward mobility+I3 progressions+I4 downward mobility-I3 deaths-I3 downward mobility-I3 upward mobility	People	*I3* represents a population of South Africans that are not attending any educational institution. People in this population have reached their highest- and final level of education. The range of average monthly household income for this population is between *R* 10,000 and *R* 14,999.
I4	I3 upward mobility+I4 progressions+I5 downward mobility-I4 deaths-I4 downward mobility-I4 upward mobility	People	*I4* represents a population of South Africans that are not attending any educational institution. People in this population have reached their highest- and final level of education. The range of average monthly household income for this population is between *R* 15,000 and *R* 19,999.
I5	I4 upward mobility+I5 progressions-I5 deaths-I5 downward mobility	People	*I5* represents a population of South Africans that are not attending any educational institution. People in this population have reached their highest- and final level of education. The range of average monthly household income for this population is *R* 20,000 and more. This is

			therefore the largest income range of the five population stocks.

Table 9.20: Specification of initial values for stocks of the income sub-model

Initial value name	Quantity	Unit	Description
I1 initial population	2.43773e+07	People	This constant represents the initial population of stock *I1* in 2008. This value was calculated from the data obtained through the 2008 General Household Survey (Statistics South Africa, 2013a).
I2 initial population	6.15124e+06	People	This constant represents the initial population of stock *I2* in 2008. This value was calculated from the data obtained through the 2008 General Household Survey (Statistics South Africa, 2013a).
I3 initial population	2.87433e+06	People	This constant represents the initial population of stock *I3* in 2008. This value was calculated from the data obtained through the 2008 General Household Survey (Statistics South Africa, 2013a).
I4 initial population	1.69789e+06	People	This constant represents the initial population of stock *I4* in 2008. This value was calculated from the data obtained through the 2008 General Household Survey (Statistics South Africa, 2013a).
I5 initial population	2.43323e+06	People	This constant represents the initial population of stock *I5* in 2008. This value was calculated from the data obtained through the 2008 General Household Survey (Statistics South Africa, 2013a).

Table 9.21: Specification of flows developed for the income sub-model

Flow name	Flow equation	Unit
I1 progressions	(LTPC dropouts*"LTPC I1 %") +(PC dropouts*"PC I1 %") +(SSNC dropouts*"SSNC I1 %") +(matriculants*"Matriculant I1 %") +(graduates*"TEC I1 %")	People/Year
I1 deaths	I1*(SA crude death rate/1000)	People/Year
I1 upward mobility	I1*I1 upward mobility rate	People/Year
I2 progressions	(LTPC dropouts*"LTPC I2 %") +(PC dropouts*"PC I2 %") +(SSNC dropouts*"SSNC I2 %") +(matriculants*"Matriculant I2 %") +(graduates*"TEC I2 %")	People/Year
I2 deaths	I2*(SA crude death rate/1000)	People/Year
I2 downward mobility	I2*I2 downward mobility rate	People/Year
I2 upward mobility	I2*I2 upward mobility rate	People/Year
I3 progressions	(LTPC dropouts*"LTPC I3 %")	People/Year

	+(PC dropouts*"PC I3 %") +(SSNC dropouts*"SSNC I3 %") +(matriculants*"Matriculant I3 %") +(graduates*"TEC I3 %")	
I3 deaths	I3*(SA crude death rate/1000)	People/Year
I3 downward mobility	I3*I3 downward mobility rate	People/Year
I3 upward mobility	I3*I3 upward mobility rate	People/Year
I4 progressions	(LTPC dropouts*"LTPC I4 %") +(PC dropouts*"PC I4 %") +(SSNC dropouts*"SSNC I4 %") +(matriculants*"Matriculant I4 %") +(graduates*"TEC I4 %")	People/Year
I4 deaths	I4*(SA crude death rate/1000)	People/Year
I4 downward mobility	I4*I4 downward mobility rate	People/Year
I4 upward mobility	I4*I4 upward mobility rate	People/Year
I5 progressions	(LTPC dropouts*"LTPC I5 %") +(PC dropouts*"PC I5 %") +(SSNC dropouts*"SSNC I5 %") +(matriculants*"Matriculant I5 %") +(graduates*"TEC I5 %")	People/Year
I5 deaths	I5*(SA crude death rate/1000)	People/Year
I5 downward mobility	I5*I5 downward mobility rate	People/Year

Table 9.22: Specification constants created for the income sub-model

Constant name	Value	Unit	Description
LTPC I1 %	0.685631	Dimensionless	The fraction of people that exit primary school before completing grade 7, through the *LTPC dropouts* flow, and progress into the *I1* population stock.
LTPC I2 %	0.162656	Dimensionless	The fraction of people that exit primary school before completing grade 7, through the *LTPC dropouts* flow, and progress into the *I2* population stock.
LTPC I3 %	0.0568594	Dimensionless	The fraction of people that exit primary school before completing grade 7, through the *LTPC dropouts* flow, and progress into the *I3* population stock.
LTPC I4 %	0.0269989	Dimensionless	The fraction of people that exit primary school before completing grade 7, through the *LTPC dropouts* flow, and progress into the *I4* population stock.
LTPC I5 %	0.0678547	Dimensionless	The fraction of people that exit primary school before completing grade 7, through the *LTPC*

			dropouts flow, and progress into the *I5* population stock.
PC I1 %	0.690911	Dimensionless	This constant represents the fraction of people that complete primary school (grade 7), but stop any further education and therefore progress to the *I1* population stock through the *PC dropouts* flow.
PC I2 %	0.171453	Dimensionless	This constant represents the fraction of people that complete primary school (grade 7), but stop any further education and therefore progress to the *I2* population stock through the *PC dropouts* flow.
PC I3 %	0.056867	Dimensionless	This constant represents the fraction of people that complete primary school (grade 7), but stop any further education and therefore progress to the *I3* population stock through the *PC dropouts* flow.
PC I4 %	0.0269409	Dimensionless	This constant represents the fraction of people that complete primary school (grade 7), but stop any further education and therefore progress to the *I4* population stock through the *PC dropouts* flow.
PC I5 %	0.0538286	Dimensionless	This constant represents the fraction of people that complete primary school (grade 7), but stop any further education and therefore progress to the *I5* population stock through the *PC dropouts* flow.
SSNC I1 %	0.646071	Dimensionless	The fraction of people that flows to the *SSNC out of school* stock and therefore progresses to the *I1* population stock to be associated with an income attribute.
SSNC I2 %	0.188714	Dimensionless	The fraction of people that flows to the *SSNC out of school* stock and therefore progresses to the *I2* population stock to be associated with an income attribute.
SSNC I3 %	0.0697095	Dimensionless	The fraction of people that flows to the *SSNC out of school* stock and therefore progresses to the *I3* population stock to be associated with an income attribute.
SSNC I4 %	0.0318385	Dimensionless	The fraction of people that flows to the *SSNC out of school* stock and therefore progresses to the *I4* population stock to be associated with an income attribute.
SSNC I5 %	0.0636672	Dimensionless	The fraction of people that flows to the *SSNC out of school* stock and therefore progresses to the *I5* population stock to be associated with an income attribute.
Matriculant I1 %	0.429029	Dimensionless	The fraction of people that flows to the *SSC out of school* stock and therefore progresses to the *I1* population stock to be associated with an income attribute.
Matriculant I2 %	0.214272	Dimensionless	The fraction of people that flows to the *SSC out of school* stock and therefore progresses to the *I2* population stock to be associated with an income attribute.

Matriculant I3 %	0.112746	Dimensionless	The fraction of people that flows to the *SSC out of school* stock and therefore progresses to the *I3* population stock to be associated with an income attribute.
Matriculant I4 %	0.064728	Dimensionless	The fraction of people that flows to the *SSC out of school* stock and therefore progresses to the *I4* population stock to be associated with an income attribute.
Matriculant I5 %	0.179225	Dimensionless	The fraction of people that flows to the *SSC out of school* stock and therefore progresses to the *I5* population stock to be associated with an income attribute.
TEC I1 %	0.122322	Dimensionless	The fraction of people that flows to the *Tertiary education completed* stock and therefore progresses to the *I1* population stock to be associated with an income attribute.
TEC I2 %	0.120222	Dimensionless	The fraction of people that flows to the *Tertiary education completed* stock and therefore progresses to the *I2* population stock to be associated with an income attribute.
TEC I3 %	0.127437	Dimensionless	The fraction of people that flows to the *Tertiary education completed* stock and therefore progresses to the *I3* population stock to be associated with an income attribute.
TEC I4 %	0.0964338	Dimensionless	The fraction of people that flows to the *Tertiary education completed* stock and therefore progresses to the *I4* population stock to be associated with an income attribute.
TEC I5 %	0.533585	Dimensionless	The fraction of people that flows to the *Tertiary education completed* stock and therefore progresses to the *I5* population stock to be associated with an income attribute.
I1 upward mobility rate	0.0017258	Dimensionless /Year	This value represents the fraction of the *I1* population stock that annually moves to the *I2* population stock, thereby exhibiting upward economic mobility.
I2 downward mobility rate	0.0096093	Dimensionless /Year	This value represents the fraction of the *I2* population stock that annually moves to the *I1* population stock, thereby exhibiting downward economic mobility.
I2 upward mobility rate	0.00142784	Dimensionless /Year	This value represents the fraction of the *I2* population stock that annually moves to the *I3* population stock, thereby exhibiting upward economic mobility.
I3 downward mobility rate	0.00552539	Dimensionless /Year	This value represents the fraction of the *I3* population stock that annually moves to the *I2* population stock, thereby exhibiting downward economic mobility.
I3 upward mobility rate	0.00115768	Dimensionless /Year	This value represents the fraction of the *I3* population stock that annually moves to the *I4*

			population stock, thereby exhibiting upward economic mobility.
I4 downward mobility rate	0.00114923	Dimensionless /Year	This value represents the fraction of the *I4* population stock that annually moves to the *I3* population stock, thereby exhibiting downward economic mobility.
I4 upward mobility rate	0.00275428	Dimensionless /Year	This value represents the fraction of the *I4* population stock that annually moves to the *I5* population stock, thereby exhibiting upward economic mobility.
I5 downward mobility rate	0.0012847	Dimensionless /Year	This value represents the fraction of the *I5* population stock that annually moves to the *I4* population stock, thereby exhibiting downward economic mobility.

9.3.3 Appendix C3

Appendix C3 contains descriptions for all variables used to create the structure represented by Figure 5.9.

Table 9.23 lists and describes the auxiliary variables used for the structure shown by Figure 5.9. Values used for auxiliary variables labelled *ia% (im)* to *va% (d5)* were derived from Van Broekhuizen *et al.* (2016: p.vi) as shown by Figure 5.10. Values for variables *ia%* to *va%* were derived from the study conducted by van Broekhuizen *et al.* (2018: p.93). Auxiliary variables of the structure were declared as type “Auxiliary” and sub-type “Normal”, unless otherwise stated. Table 9.24 lists and describes the constants used for the structure shown by Figure 5.9. The values of these constants were derived from data obtained through the General Household Survey of 2008 (Statistics South Africa, 2013a). All constants were declared as type “Constant” and sub-type “Normal”.

Table 9.23: Specification of auxiliary variables created for the structure representing the influence of the income sub-model on the immediate- and delayed tertiary education access rates of the education sub-model

Variable name	Variable equation	Unit	Description
i	(i%)*I1	People	This variable is a preliminary estimation of the grade 12 population living in households with an income of less than *R* 5,000 per month.
ii	(ii%)*I2	People	This variable is a preliminary estimation of the grade 12 population living in households with an income between *R* 5,000 and *R* 9,999 per month.
iii	(iii%)*I3	People	This variable is a preliminary estimation of the grade 12 population living in households with an income between *R* 10,000 and *R* 14,999 per month.
iv	(iv%)*I4	People	This variable is a preliminary estimation of the grade 12 population living in households with

			an income between *R* 15,000 and *R* 19,999 per month.
v	(v%)*I5	People	This variable is a preliminary estimation of the grade 12 population living in households with an income of more than *R* 20,000 per month.
i-v Total	i+ii+iii+iv+v	People	This variable sums up the preliminarily estimated grade 12 population sizes according to the five average monthly household income categories.
grade 12 population	Secondary school population*grade 12 ratio	People	This variable estimates the size of the grade 12 population size according to the size of the secondary school population stock.
I Grade 12	(i/"i-v Total")*grade 12 population	People	This variable estimates the size of the current grade 12 population that lives in households of an average monthly income of less than *R* 5,000 by taking into account the size of the current entire grade 12 population.
II Grade 12	(ii/"i-v Total")*grade 12 population	People	This variable estimates the size of the current grade 12 population that lives in households of an average monthly income between *R* 5,000 and *R* 9,999 by taking into account the size of the current entire grade 12 population.
III Grade 12	(iii/"i-v Total")*grade 12 population	People	This variable estimates the size of the current grade 12 population that lives in households of an average monthly income between *R* 10,000 and *R* 14,999 by taking into account the size of the current entire grade 12 population.
IV Grade 12	(iv/"i-v Total")*grade 12 population	People	This variable estimates the size of the current grade 12 population that lives in households of an average monthly income between *R* 15,000 and *R* 19,999 by taking into account the size of the current entire grade 12 population.
V Grade 12	(v/"i-v Total")*grade 12 population	People	This variable estimates the size of the current grade 12 population that lives in households of an average monthly of more than *R* 20,000 by taking into account the size of the current entire grade 12 population.
fa (im)	(I Grade 12*"ia% (im)")+ (II Grade 12*"iia% (im)")+	People/ Year	This variable sums up the total number of matriculants, from all income levels, that will access

	(III Grade 12*"iiia% (im)")+ (IV Grade 12*"iva% (im)")+ (V Grade 12*"va% (im)")		tertiary education immediately after completing matric.
fa (d1)	(I Grade 12*"ia% (d1)")+ (II Grade 12*"iia% (d1)")+ (III Grade 12*"iiia% (d1)")+ (IV Grade 12*"iva% (d1)")+ (V Grade 12*"va% (d1)")	People/ Year	This variable sums up the total number of matriculants, from all income levels, that will delay enrolment at tertiary education institutions by one year.
fa (d2)	(I Grade 12*"ia% (d2)")+ (II Grade 12*"iia% (d2)")+ (III Grade 12*"iiia% (d2)")+ (IV Grade 12*"iva% (d2)")+ (V Grade 12*"va% (d2)")	People/ Year	This variable sums up the total number of matriculants, from all income levels, that will delay enrolment at tertiary education institutions by two years.
fa (d3)	(I Grade 12*"ia% (d3)")+ (II Grade 12*"iia% (d3)")+ (III Grade 12*"iiia% (d3)")+ (IV Grade 12*"iva% (d3)")+ (V Grade 12*"va% (d3)")	People/ Year	This variable sums up the total number of matriculants, from all income levels, that will delay enrolment at tertiary education institutions by three years.
fa (d4)	(I Grade 12*"ia% (d4)")+ (II Grade 12*"iia% (d4)")+ (III Grade 12*"iiia% (d4)")+ (IV Grade 12*"iva% (d4)")+ (V Grade 12*"va% (d4)")	People/ Year	This variable sums up the total number of matriculants, from all income levels, that will delay enrolment at tertiary education institutions by four years.
fa (d5)	(I Grade 12*"ia% (d5)")+ (II Grade 12*"iia% (d5)")+ (III Grade 12*"iiia% (d5)")+ (IV Grade 12*"iva% (d5)")+ (V Grade 12*"va% (d5)")	People/ Year	This variable sums up the total number of matriculants, from all income levels, that will delay enrolment at tertiary education institutions by five years.
immediate enrolments	fa (im)	People/ Year	This variable is equivalent to the previously listed variable *fa (im)*. The *immediate enrolments* variable has been created to present a clearer name that may be understood more easily when used in conjunction with other sub-models.
fa (d1) delayed	"fa (d1)", 1 , 20240	People/ Year	This variable creates a one year fixed tertiary education access delay for the people calculated by *fa (d1)*. The variable has been declared as type "Level" and sub-type "Fixed Delay". The initial value was estimated from simulation results created without any delay in enrolments.
fa (d2) delayed	"fa (d2)", 2 , 8205	People/ Year	This variable creates a two year fixed tertiary education access delay for the people calculated by *fa (d2)*.

			The variable has been declared as type "Level" and sub-type "Fixed Delay". The initial value was estimated from simulation results created without any delay in enrolments.
fa (d3) delayed	"fa (d3)", 3 , 4376	People/ Year	This variable creates a three year fixed tertiary education access delay for the people calculated by *fa (d3)*. The variable has been declared as type "Level" and sub-type "Fixed Delay". The initial value was estimated from simulation results created without any delay in enrolments.
fa (d4) delayed	"fa (d4)", 4 , 3282	People/ Year	This variable creates a four year fixed tertiary education access delay for the people calculated by *fa (d4)*. The variable has been declared as type "Level" and sub-type "Fixed Delay". The initial value was estimated from simulation results created without any delay in enrolments.
fa (d5) delayed	"fa (d5)", 5 , 2188	People/ Year	This variable creates a five year fixed tertiary education access delay for the people calculated by *fa (d5)*. The variable has been declared as type "Level" and sub-type "Fixed Delay". The initial value was estimated from simulation results created without any delay in enrolments.
delayed enrolments	"fa (d1) delayed"+"fa (d2) delayed"+"fa (d3) delayed"+"fa (d4) delayed"+"fa (d5) delayed"	People/ Year	This variable sums up the total number of matriculants that delay their enrolment at tertiary education institutions between one and five years.
ia% (im)	"ia%"*(0.13*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income of less than *R* 5,000, that access tertiary education immediately after matriculating.
iia% (im)	"iia%"*(0.13*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income between *R* 5,000 and *R* 9,999, that access tertiary education immediately after matriculating.
iiia% (im)	"iiia%"*(0.13*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income

			between *R* 10,000 and *R* 14,999, that access tertiary education immediately after matriculating.
iva% (im)	"iva%"*(0.13*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income between *R* 15,000 and *R* 19,999, that access tertiary education immediately after matriculating.
va% (im)	"va%"*(0.13*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income of more than *R* 20,000, that access tertiary education immediately after matriculating.
ia% (d1)	"ia%"*(0.037*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income of less than *R* 5,000, that delay tertiary education enrolment for one year after matriculating.
iia% (d1)	"iia%"*(0.037*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income between *R* 5,000 and *R* 9,999, that delay tertiary education enrolment for one year after matriculating.
iiia% (d1)	"iiia%"*(0.037*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income between *R* 10,000 and *R* 14,999, that delay tertiary education enrolment for one year after matriculating.
iva% (d1)	"iva%"*(0.037*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income between *R* 15,000 and *R* 19,999, that delay tertiary education enrolment for one year after matriculating.
va% (d1)	"va%"*(0.037*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income of more than *R* 20,000, that delay tertiary education enrolment for one year after matriculating.
ia% (d2)	"ia%"*(0.015*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income of less than *R* 5,000, that delay tertiary

			education enrolment for two years after matriculating.
iia% (d2)	"iia%"*(0.015*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income between *R* 5,000 and *R* 9,999, that delay tertiary education enrolment for two years after matriculating.
iiia% (d2)	"iiia%"*(0.015*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income between *R* 10,000 and *R* 14,999, that delay tertiary education enrolment for two years after matriculating.
iva% (d2)	"iva%"*(0.015*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income between *R* 15,000 and *R* 19,999, that delay tertiary education enrolment for two years after matriculating.
va% (d2)	"va%"*(0.015*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income of more than *R* 20,000, that delay tertiary education enrolment for two years after matriculating.
ia% (d3)	"ia%"*(0.008*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income of less than *R* 5,000, that delay tertiary education enrolment for three years after matriculating.
iia% (d3)	"iia%"*(0.008*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income between *R* 5,000 and *R* 9,999, that delay tertiary education enrolment for three years after matriculating.
iiia% (d3)	"iiia%"*(0.008*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income between *R* 10,000 and *R* 14,999, that delay tertiary education enrolment for three years after matriculating.
iva% (d3)	"iva%"*(0.008*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income between *R* 15,000 and *R* 19,999, that delay tertiary education

			enrolment for three years after matriculating.
va% (d3)	"va%"*(0.008*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income of more than *R* 20,000, that delay tertiary education enrolment for three years after matriculating.
ia% (d4)	"ia%"*(0.006*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income of less than *R* 5,000, that delay tertiary education enrolment for four years after matriculating.
iia% (d4)	"iia%"*(0.006*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income between *R* 5,000 and *R* 9,999, that delay tertiary education enrolment for four years after matriculating.
iiia% (d4)	"iiia%"*(0.006*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income between *R* 10,000 and *R* 14,999, that delay tertiary education enrolment for four years after matriculating.
iva% (d4)	"iva%"*(0.006*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income between *R* 15,000 and *R* 19,999, that delay tertiary education enrolment for four years after matriculating.
va% (d4)	"va%"*(0.006*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income of more than *R* 20,000, that delay tertiary education enrolment for four years after matriculating.
ia% (d5)	"ia%"*(0.004*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income of less than *R* 5,000, that delay tertiary education enrolment for five years after matriculating.
iia% (d5)	"iia%"*(0.004*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income between *R* 5,000 and *R* 9,999, that delay tertiary education enrolment for five years after matriculating.

iiia% (d5)	"iiia%"*(0.004*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income between *R* 10,000 and *R* 14,999, that delay tertiary education enrolment for five years after matriculating.
iva% (d5)	"iva%"*(0.004*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income between *R* 15,000 and *R* 19,999, that delay tertiary education enrolment for five years after matriculating.
va% (d5)	"va%"*(0.004*5)	Dimensionless /Year	This variable calculates the fraction of matriculants, living in households with an average monthly income of more than *R* 20,000, that delay tertiary education enrolment for five years after matriculating.
ia%	0.0845441*(1+"Government long-term response")	Dimensionless /Year	This variable represents the percentage of grade 12 learners, living in households with an average monthly income of less than *R* 5,000, that access tertiary education within six years of completing matric.
iia%	0.156667*(1+"Government long-term response")	Dimensionless /Year	This variable represents the percentage of grade 12 learners, living in households with an average monthly income between *R* 5,000 and *R* 9,999, that access tertiary education within six years of completing matric.
iiia%	0.301333*(1+"Government long-term response")	Dimensionless /Year	This variable represents the percentage of grade 12 learners, living in households with an average monthly income between *R* 10,000 and *R* 14,999, that access tertiary education within six years of completing matric.
iva%	0.301333*(1+"Government long-term response")	Dimensionless /Year	This variable represents the percentage of grade 12 learners, living in households with an average monthly income between *R* 10,000 and *R* 14,999, that access tertiary education within six years of completing matric.
va%	0.425952*(1+"Government long-term response")	Dimensionless /Year	This variable represents the percentage of grade 12 learners, living in households with an average monthly income of more than *R* 20,000, that access tertiary

			education within six years of completing matric.

Table 9.24: Specification constants created for the structure representing the influence of the income sub-model on the immediate- and delayed tertiary education access rates of the education sub-model

Constant name	Value	Unit	Description
i%	0.0176119	Dimensionless	This constant represents a fraction used for the preliminary estimation of the number of grade 12 learners that live in households with an average monthly household income of less than *R* 5,000.
ii%	0.0169986	Dimensionless	This constant represents a fraction used for the preliminary estimation of the number of grade 12 learners that live in households with an average monthly household income between *R* 5,000 and *R* 9,999.
iii%	0.018556	Dimensionless	This constant represents a fraction used for the preliminary estimation of the number of grade 12 learners that live in households with an average monthly household income between *R* 10,000 and *R* 14,999.
iv%	0.01647	Dimensionless	This constant represents a fraction used for the preliminary estimation of the number of grade 12 learners that live in households with an average monthly household income between *R* 15,000 and *R* 19,999.
v%	0.0288867	Dimensionless	This constant represents a fraction used for the preliminary estimation of the number of grade 12 learners that live in households with an average monthly household income of more than *R* 20,000.

9.3.4 Appendix C4

Appendix C4 contains tables and figures describing all variables used to create the crime sub-model as shown in Figure 5.11.

Table 9.25 provides an overview of the stocks used for the crime sub-model regarding the formulation of equations and specification of units. All stocks were specified as variables of type “Level” and sub-type “Normal”. Table 9.25 contains the equations of the stocks as they are specified in the equation editor. All initial conditions specified for the stocks of the education sub-model are described in Table 9.26. Variables acting as initial conditions were declared as type “Constant” with sub-type “Normal”. Table 9.27 lists the equations and units for all flows of the education sub-model. Flow variables are declared as “Auxiliary” type and “Normal” sub-type. Equations of flows are presented as specified in the equation editor window. Table 9.28 lists the auxiliary variables of the education sub-model. The auxiliary variables are declared as type “Auxiliary” and sub-type “Normal”. Table 9.29 lists and describes the constants used for the crime sub-model. All constants were declared as type “Constant” and sub-type “Normal”.

Table 9.25: Specification of stocks developed for the crime sub-model

Stock name	Stock equation	Units	Description
Cumulative incidents of robbery (due to HII strain)	"incidents of robbery (due to HII strain)"	Robberies	This stock accumulates all incidents of robbery that occur due to household income inequality strain.
Culture of crime and violence	growth of criminal and violent culture-shrinkage of criminal and violent culture	CV culture	This stock acts as an indicator of the level of criminal and violent culture present in the South African society.
Perceived incidents	change in perceived incidents	Robberies	This stock represents number of robbery incidents that the government authorities perceive as current.

Table 9.26: Specification of initial values for stocks of the crime sub-model

Initial value name	Quantity	Unit	Description
initial incidents of robbery (due to HII strain)	10000	Robberies	This constant specifies the initial value of the *Cumulative incidents of robbery (due to HII strain)* stock at the beginning of the simulation.
initial culture of crime and violence	900	CV culture	This constant specifies the initial value of the *Culture of crime and violence* stock at the beginning of the simulation.
initial perceived incidents	2200	Robberies	This constant specifies the initial value of the *Perceived incidents* stock at the beginning of the simulation.

Table 9.27: Specification of flows developed for the crime sub-model

Flow name	Flow equation	Unit
incidents of robbery (due to HII strain)	(opportunity to commit robbery*(1-"Government short-term response"))*need to commit robbery*mindset of using robbery as a means to reduce HII strain	Robberies /Year
growth of criminal and violent culture	(1-(Culture of crime and violence/maximum culture of crime and violence))*"incidents of robbery (due to HII strain)"*criminal and violent culture sustenance factor	(CV culture) /Year
shrinkage of criminal and violent culture	Culture of crime and violence/culture fade time	(CV culture) /Year
change in perceived incidents	robbery perception error/perception adjustment time	Robberies /Year

Table 9.28: Specification auxiliary variables created for the crime sub-model

Variable name	Variable equation	Unit	Description
need to commit robbery	"Income Inequality Indicator (III) relation to HII strain	Dimensionless	This variable calculates a supposed need of individuals to commit robbery due to household income inequality,

	TABLE"("Income Inequality Indicator (III)")/Maximum HII strain		measured by the Income Inequality Indicator.
mindset of using robbery as a means to reduce HII strain	Culture of crime and violence/maximum culture of crime and violence	Dimensionless	This variable is used to provide a measure of people's mindsets regarding the use of robbery as a means to reduce strain caused by household income inequality. This is measured according to the level of crime and violence present in society.
robbery perception error	("incidents of robbery (due to HII strain)"*reporting interval)-Perceived incidents	Robberies	This variable calculates the difference between the current actual incidents of robbery and the currently perceived incidents of robbery.
incident saturation ratio	(Perceived incidents/opportunity period)/opportunity to commit robbery	Dimensionless	This ratio provides an indication of the level of crime and violence, by comparing perceived number of robberies with the number of robbery opportunities.
Government long-term response	"Government long-term response TABLE"(incident saturation ratio)	Dimensionless /Year	The long-term government response to the number of robbery incidents affects the tertiary education access rates of the education sub-model.
Government short-term response	"Government short-term response TABLE"(incident saturation ratio)	Dimensionless	The short-term government response to the number of robbery incidents affects the number opportunities to commit robbery.
opportunity period	reporting interval	Year	The *opportunity period* represents the time window within which the perceived incidents of robbery occurred. It is therefore equal to the *reporting interval*.

Table 9.29: Specification constants created for the crime sub-model

Constant name	Value	Unit	Description
Maximum HII strain	1	Strain	For this model, strain is represented as a ratio from zero to one. Zero strain represents no strain at all and a strain of one represents the maximum amount of strain that can be experienced due household income inequality.
criminal and violent culture sustenance factor	0.1	CV culture /Robberies	This factor is a representation of the sustaining effect that incidents of robbery have on the culture of crime and violence in the society. Each robbery increases
maximum culture of crime and violence	1000	CV culture	This constant represents the maximum level of criminal and violent culture that can exist in the society.

culture fade time	20	Year	This constant represents the number of years it takes for a unit of criminal and violent culture to fade from the minds of the society.
opportunity to commit robbery	25000	Robberies /Year	This constant represents the number of opportunities for robbery to occur within a year.
reporting interval	1	Year	The *reporting interval* represents the time that passes between the reporting of new incidents of robbery.
perception adjustment time	1/12	Year	This constant represents the time required for all relevant government authorities to be informed of new incidents of robbery.

All variables used as lookup functions were declared as type “Lookup”. The variable *Income Inequality Indicator (III) relation to HII strain TABLE* is declared as a lookup function with the unit *Strain*. This variable is implemented to represent relationship between the Income Inequality Indicator (III) and the strain put on an individual as a result of household income inequality. This relationship was assumed to exist as an exponential function that was estimated as shown in Figure 9.6. The relationship is assumed to be exponential, because it is assumed that the rate at which strain increases, increases as income inequality increases.

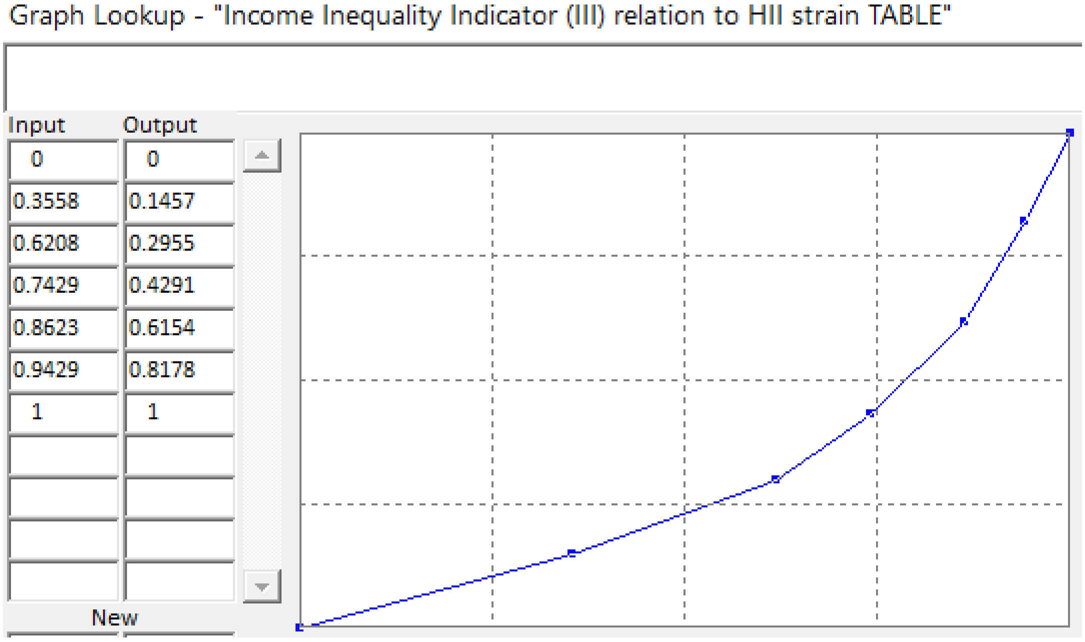

Figure 9.6: Lookup function specified for “Income Inequality Indicator (III) relation to HII strain TABLE”

The variable *Government long-term response TABLE* is also declared as a lookup function with the unit *Dimensionless/Year*. The variable is implemented to represent how the government’s long-term response is influenced by the perceived number of robberies occurring, as given by the *incident saturation ratio*. This influence was assumed to exist as a linear function that was estimated as shown in Figure 9.7. The figure shows that the maximum effect that the long-term response can have, is a 20 % increase in tertiary education access rates for grade 12 pupils from all income categories. This minimal effect was assumed to represent an optimistic view of the government’s current approach and priority regarding the improvement of tertiary education access to prevent robbery occurring in the long run. The relationship in essence means that as the number of robbery incidents increases, the government’s long term response increases.

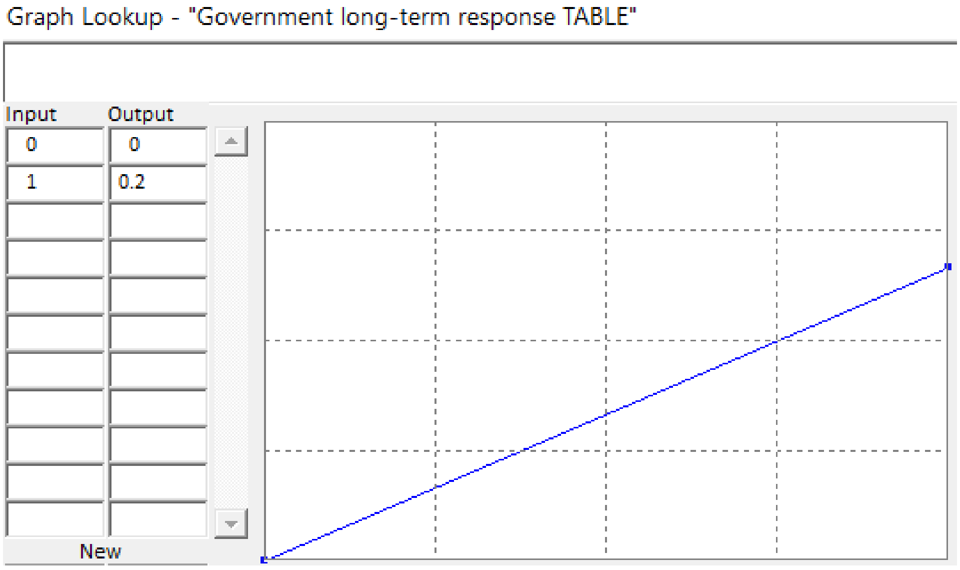

Figure 9.7: Lookup function specified for "Government long-term response TABLE"

The variable *Government short-term response TABLE* represents the influence of the perceived number of robberies on the government's short-term response strategy. The variable is declared as a lookup function, with a dimensionless unit, and this influence is assumed to exist as a step function, as shown in Figure 9.8. It was assumed that the government takes action to reduce opportunities of robbery according to six crime "levels". These levels were defined as ranges of the robbery *incident saturation ratio*. This means that as a certain range of robbery incidents is reached, a corresponding level of government response is initiated. This relationship in essence means that as the number of robbery incidents increases, the government's short term response increases.

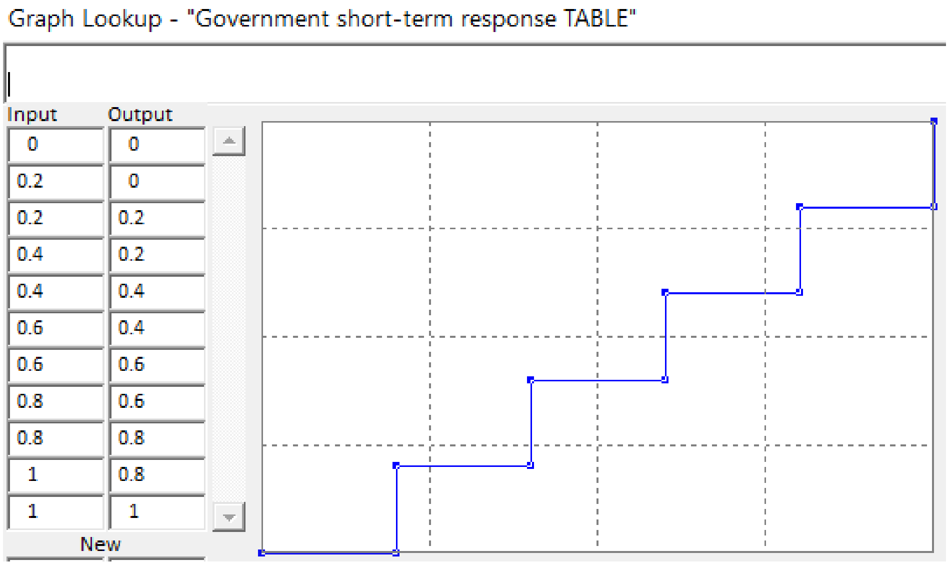

Figure 9.8: Lookup function specified for "Government short-term response TABLE"

9.3.5 Appendix C5

This appendix contains tables and figures describing all variables used to calculate the Lorenz curve points and the Income Inequality Indicator (III) as defined in the simulation model for this study.

Table 9.30 lists the auxiliary variables used for the structure that estimates Lorenz curve points from the income category stocks of the income sub-model. The auxiliary variables are declared as type "Auxiliary" and sub-type "Normal". Table 9.31 lists and describes the constants used for the structure that estimates Lorenz curve points from the income category stocks of the income sub-model. All constants were declared as type "Constant" and sub-type "Normal".

Table 9.30: Specification auxiliary variables created for the calculation of Lorenz curve points

Variable name	Variable equation	Unit	Description
I1 households	I1/Average Household Size in South Africa	Household	An estimation of the number of South African households with an average monthly income of less than *R* 5,000.
I2 households	I2/Average Household Size in South Africa	Household	An estimation of the number of South African households with an average monthly income between *R* 5,000 and *R* 9,999.
I3 households	I3/Average Household Size in South Africa	Household	An estimation of the number of South African households with an average monthly income between *R* 10,000 and *R* 14,999.
I4 households	I4/Average Household Size in South Africa	Household	An estimation of the number of South African households with an average monthly income between *R* 15,000 and *R* 19,999.
I5 households	I5/Average Household Size in South Africa	Household	An estimation of the number of South African households with an average monthly income of more than *R* 20,000.
Total households	I1 households +I2 households +I3 households +I4 households +I5 households	Household	An estimation of the total number of households in South Africa.
I1 cumulative % households	I1 households/Total households	Dimensionless	A representation of the cumulative percentage of households consisting of *I1 households*.
I2 cumulative % households	"I1 cumulative % households" +(I2 households/Total households)	Dimensionless	A representation of the cumulative percentage of households consisting of *I1*- and *I2 households*.
I3 cumulative % households	"I2 cumulative % households" +(I3 households/Total households)	Dimensionless	A representation of the cumulative percentage of households consisting of *I1*-, *I2*- and *I3 households*.
I4 cumulative % households	"I3 cumulative % households" +(I4 households/Total households)	Dimensionless	A representation of the cumulative percentage of households consisting of *I1*-, *I2*-, *I3*- and *I4 households*.

"I5 cumulative % households"	"I4 cumulative % households" +(I5 households/Total households)	Dimensionless	A representation of the cumulative percentage of households consisting of *I1-*, *I2-*, *I3-*, *I4-* and *I5 households*.
I1 income	I1 average monthly household income*I1 households	Rand	An estimation of the total monthly income of all *I1 households*.
I2 income	(I2 average monthly household income*I2 households)	Rand	An estimation of the total monthly income of all *I2 households*.
I3 income	(I3 average monthly household income*I3 households)	Rand	An estimation of the total monthly income of all *I3 households*.
I4 income	(I4 average monthly household income*I4 households)	Rand	An estimation of the total monthly income of all *I4 households*.
I5 income	(I5 average monthly household income*I5 households)	Rand	An estimation of the total monthly income of all *I5 households*.
Total monthly income	I1 income +I2 income +I3 income +I4 income +I5 income	Rand	An estimation of the total monthly income generated by households from all income categories.
I1 cumulative % income	I1 income/Total monthly income	Dimensionless	A representation of the cumulative percentage of income generated by *I1 households*.
I2 cumulative % income	"I1 cumulative % income" +(I2 income/Total monthly income)	Dimensionless	A representation of the cumulative percentage of income generated by *I1-* and *I2 households*.
I3 cumulative % income	"I2 cumulative % income" +(I3 income/Total monthly income)	Dimensionless	A representation of the cumulative percentage of income generated by *I1-*, *I2-* and *I3 households*.
I4 cumulative % income	"I3 cumulative % income" +(I4 income/Total monthly income)	Dimensionless	A representation of the cumulative percentage of income generated by *I1-*, *I2-*, *I3-* and *I4 households*.
I5 cumulative % income	"I4 cumulative % income" +(I5 income/Total monthly income)	Dimensionless	A representation of the cumulative percentage of income generated by *I1-*, *I2-*, *I3-*, *I4-* and *I5 households*.

Table 9.31: Specification constants created for the calculation of Lorenz curve points

Constant name	Value	Unit	Description
Average Household Size in South Africa	3.3	People /Household	This is the estimated average household size in South Africa for 2019 (Africa GeoPortal, 2019).
I1 average monthly household income	2500	Rand /Household	An estimation of the average monthly household income for *I1 households*.
I2 average monthly household income	7500	Rand /Household	An estimation of the average monthly household income for *I2 households*.
I3 average monthly household income	12500	Rand /Household	An estimation of the average monthly household income for *I3 households*.
I4 average monthly household income	17500	Rand /Household	An estimation of the average monthly household income for *I4 households*.
I5 average monthly household income	22500	Rand /Household	An estimation of the average monthly household income for *I5 households*.

Table 9.32 lists the auxiliary variables used for the structure that estimates the Income Inequality Indicator (III) from the previously calculated Lorenz curve points according to Equation (1). The auxiliary variables are declared as type “Auxiliary” and sub-type “Normal”. Table 9.33 lists and describes the constants used for the structure that estimates the Income Inequality Indicator (III) from the previously calculated Lorenz curve points according to Equation (1). All constants were declared as type “Constant” and sub-type “Normal”.

Table 9.32: Specification auxiliary variables created for the Income Inequality Indicator (III) calculation

Variable name	Variable equation	Unit	Description
X1	"I1 cumulative % households"	Dimensionless	This represents variable X_k when k=1 and X_{k-1} when k=2 for Equation (1).
X2	"I2 cumulative % households"	Dimensionless	This represents variable X_k when k=2 and X_{k-1} when k=3 for Equation (1).
X3	"I3 cumulative % households"	Dimensionless	This represents variable X_k when k=3 and X_{k-1} when k=4 for Equation (1).
X4	"I4 cumulative % households"	Dimensionless	This represents variable X_k when k=4 and X_{k-1} when k=5 for Equation (1).
X5	"I5 cumulative % households"	Dimensionless	This represents variable X_k when k=5 for Equation (1).
Y1	"I1 cumulative % income"	Dimensionless	This represents variable Y_k when k=1 and Y_{k-1} when k=2 for Equation (1).
Y2	"I2 cumulative % income"	Dimensionless	This represents variable Y_k when k=2 and Y_{k-1} when k=3 for Equation (1).

Y3	"I3 cumulative % income"	Dimensionless	This represents variable Y_k when k=3 and Y_{k-1} when k=4 for Equation (1).
Y4	"I4 cumulative % income"	Dimensionless	This represents variable Y_k when k=4 and Y_{k-1} when k=5 for Equation (1).
Y5	"I5 cumulative % income"	Dimensionless	This represents variable Y_k when k=5 for Equation (1).
X1-X0	X1-X0	Dimensionless	This represents $(X_k - X_{k-1})$ when k=1 for Equation (1).
X2-X1	X2-X1	Dimensionless	This represents $(X_k - X_{k-1})$ when k=2 for Equation (1).
X3-X2	X3-X2	Dimensionless	This represents $(X_k - X_{k-1})$ when k=3 for Equation (1).
X4-X3	X4-X3	Dimensionless	This represents $(X_k - X_{k-1})$ when k=4 for Equation (1).
X5-X4	X5-X4	Dimensionless	This represents $(X_k - X_{k-1})$ when k=5 for Equation (1).
Y1+Y0	Y1+Y0	Dimensionless	This represents $(Y_k + Y_{k-1})$ when k=1 for Equation (1).
Y2+Y1	Y2+Y1	Dimensionless	This represents $(Y_k + Y_{k-1})$ when k=2 for Equation (1).
Y3+Y2	Y3+Y2	Dimensionless	This represents $(Y_k + Y_{k-1})$ when k=3 for Equation (1).
Y4+Y3	Y4+Y3	Dimensionless	This represents $(Y_k + Y_{k-1})$ when k=4 for Equation (1).
Y5+Y4	Y5+Y4	Dimensionless	This represents $(Y_k + Y_{k-1})$ when k=5 for Equation (1).
k=1	"X1-X0"*"Y1+Y0"	Dimensionless	This represents $(X_k - X_{k-1})$ $(Y_k + Y_{k-1})$ when k=1 for Equation (1).
k=2	"X2-X1"*"Y2+Y1"	Dimensionless	This represents $(X_k - X_{k-1})$ $(Y_k + Y_{k-1})$ when k=2 for Equation (1).
k=3	"X3-X2"*"Y3+Y2"	Dimensionless	This represents $(X_k - X_{k-1})$ $(Y_k + Y_{k-1})$ when k=3 for Equation (1).
k=4	"X4-X3"*"Y4+Y3"	Dimensionless	This represents $(X_k - X_{k-1})$ $(Y_k + Y_{k-1})$ when k=4 for Equation (1).
k=5	"X5-X4"*"Y5+Y4"	Dimensionless	This represents $(X_k - X_{k-1})$ $(Y_k + Y_{k-1})$ when k=5 for Equation (1).
Income Inequality Indicator (III)	1-("k=1"+"k=2"+"k=3"+"k=4"+"k=5")	Dimensionless	This is the representation of the Income Inequality Indicator (III) as formulated in Equation (1).

Table 9.33: Specification constants created for the Income Inequality Indicator (III) calculation

Constant name	Value	Unit	Description
X0	0	Dimensionless	This represents variable X_{k-1} when k=1 for Equation (1).
Y0	0	Dimensionless	This represents variable Y_{k-1} when k=1 for Equation (1).

9.4 Appendix D

Appendix D contains several iterations of the causal loop diagram for the model, as well as documentation iteratively used to conduct semi-structured interviews with South African criminologists regarding the adequacy of the causal loop diagram.

9.4.1 Appendix D1

Appendix D1 contains several previous iterations of the causal loop diagram for the simulation model. Figure 9.9 - Figure 9.13 show a snapshot of how the dynamic hypothesis evolved over time. The shown causal loop diagrams of course only represent a small selection of all causal loop diagrams developed throughout the study.

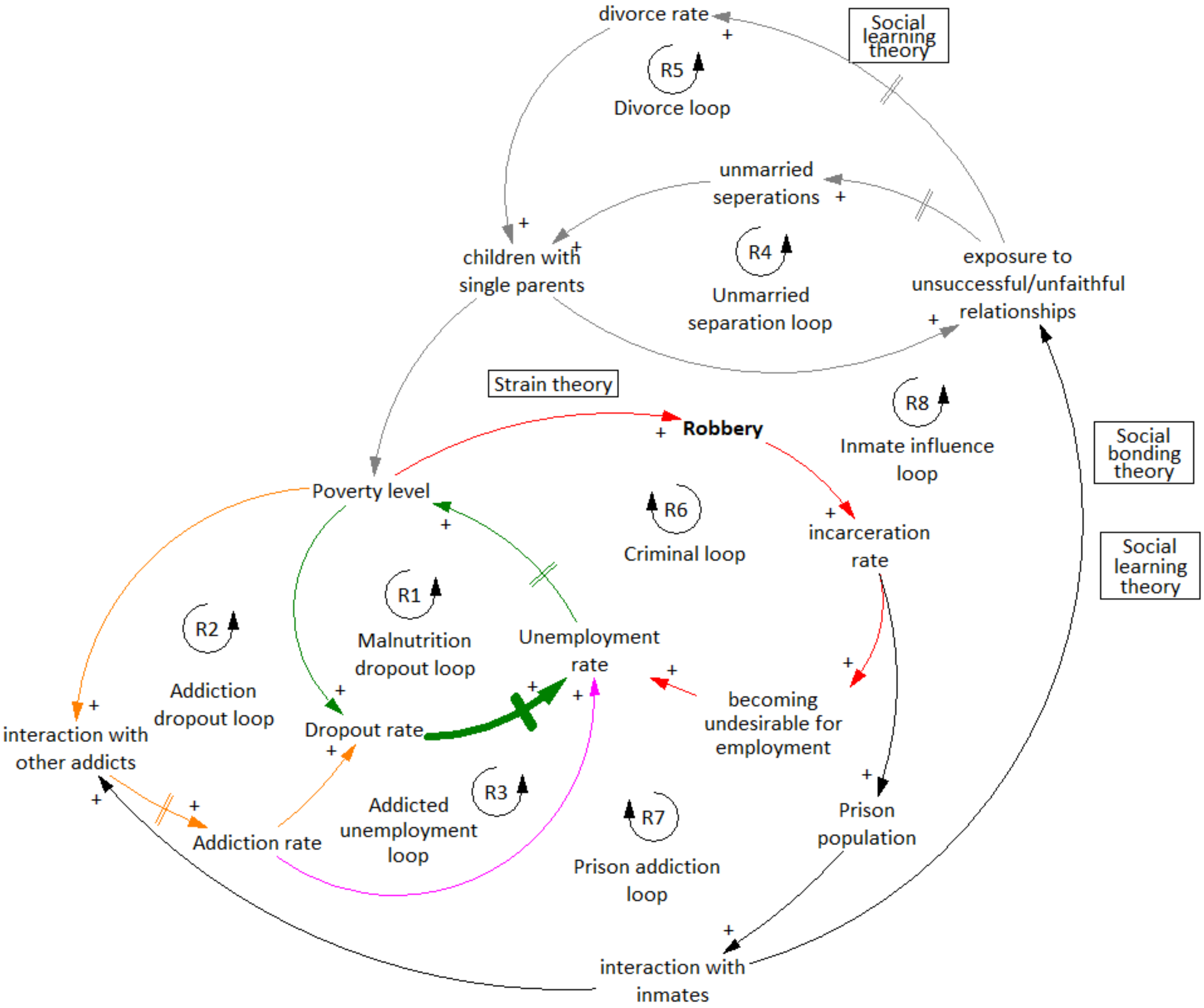

Figure 9.9: First iteration of causal loop diagram

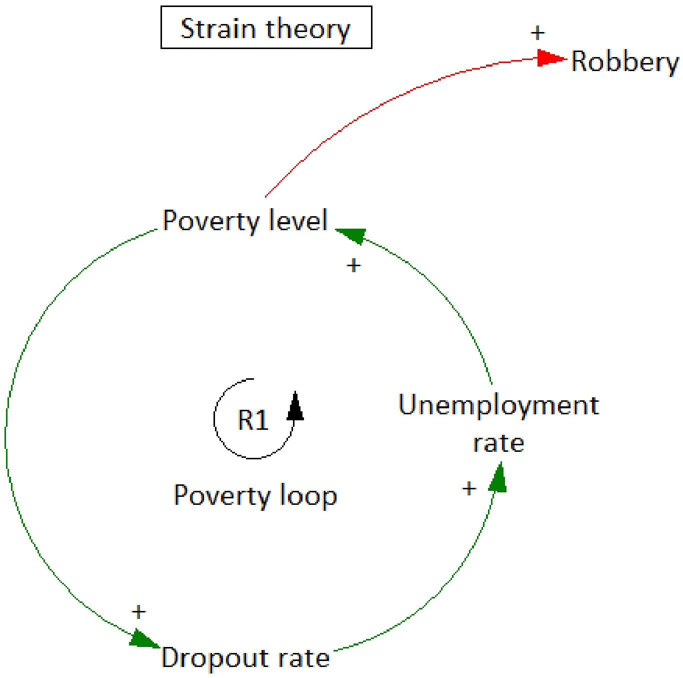

Figure 9.10: Second iteration of causal loop diagram

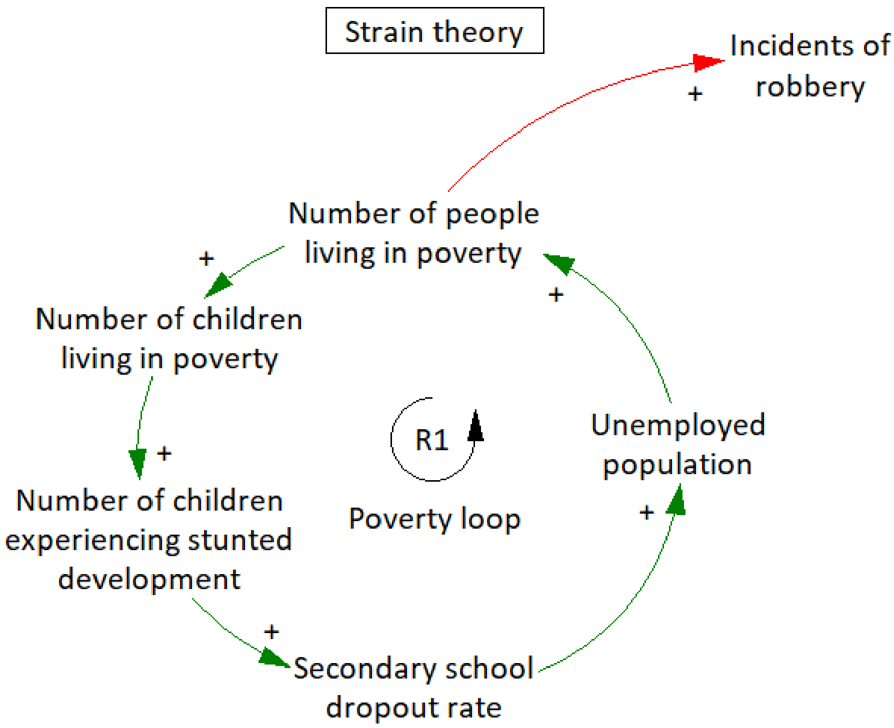

Figure 9.11: Third iteration of causal loop diagram

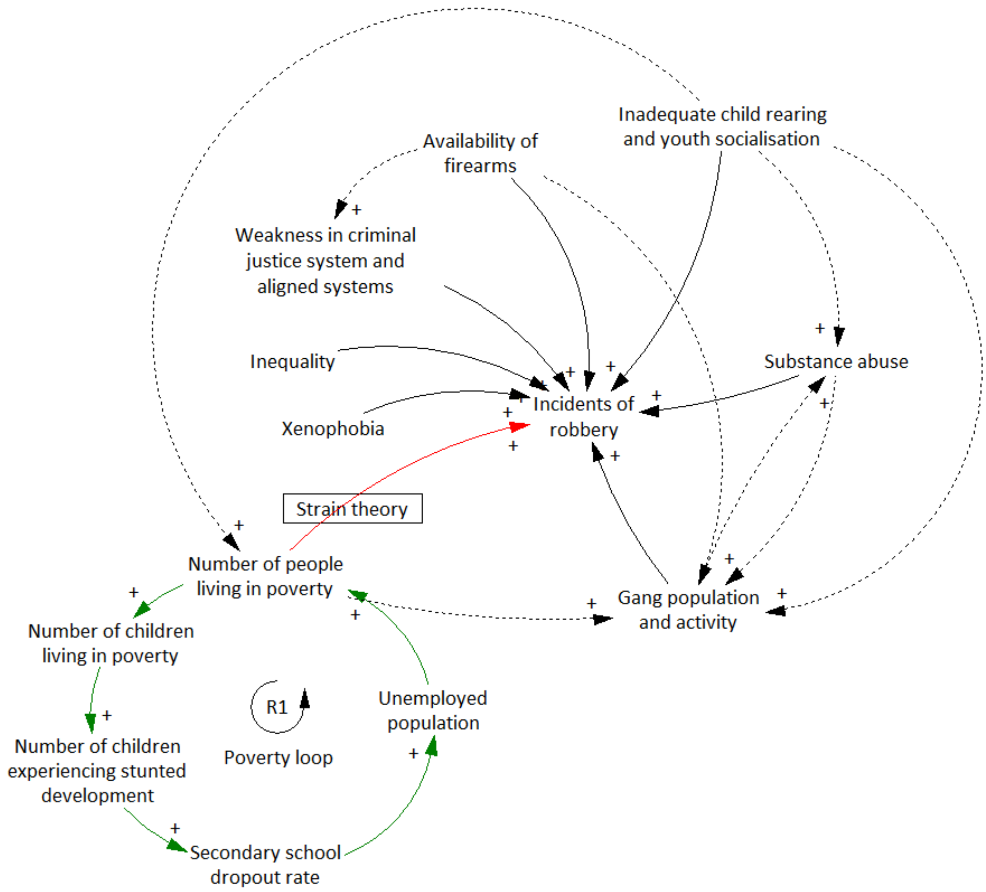

Figure 9.12: Fourth iteration of causal loop diagram

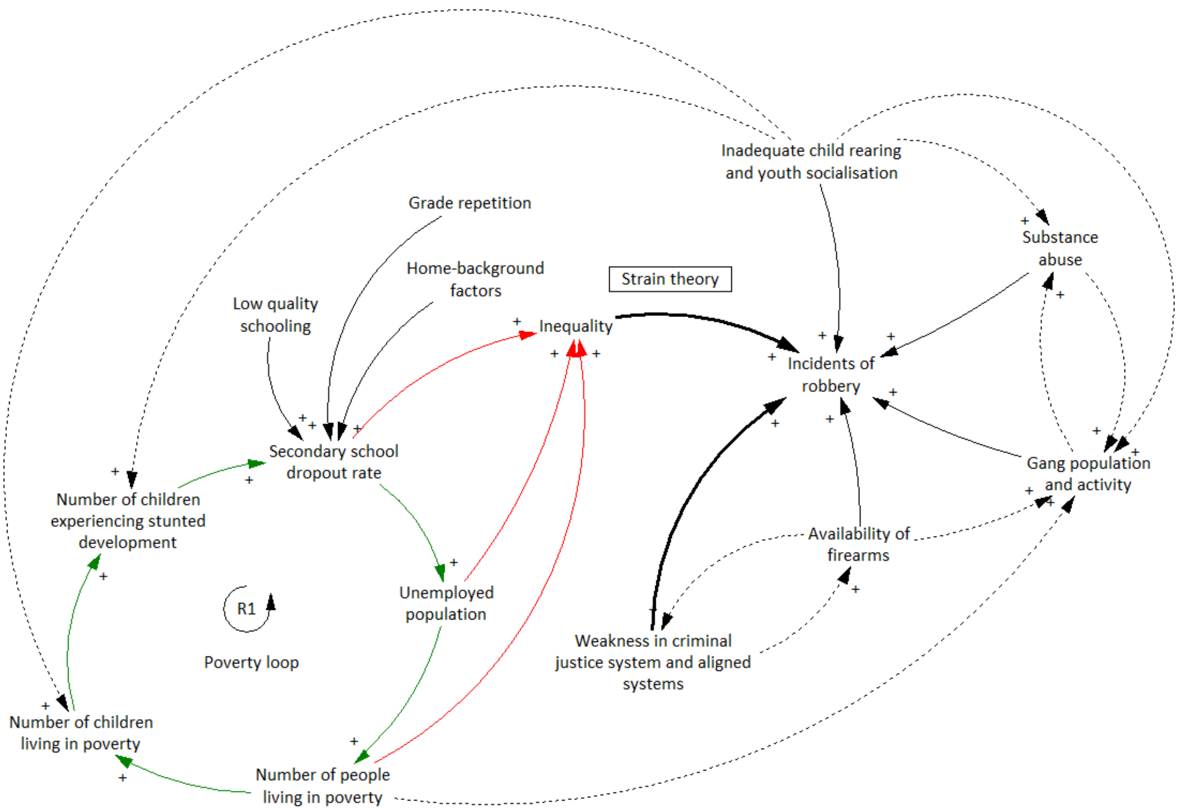

Figure 9.13: Fifth iteration of causal loop diagram

9.4.2 Appendix D2

Appendix D2 contains the written consent declaration developed to receive ethical clearance for project number (10190) from the Research Ethics Committee (REC) of Stellenbosch University. Criminologists were only interviewed once written consent was received.

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CONSENT TO PARTICIPATE IN RESEARCH

You are invited to take part in a study conducted by Felix Adam, from the Industrial Engineering Department, specifically the research group Health Systems Engineering and Innovation, at Stellenbosch University. You were approached as a possible participant, because of your expertise in the field of criminology.

1. **PURPOSE OF THE STUDY**

The study investigates poverty as a cause of robbery in the South Africa. Strain theory was used as the theoretical basis for the conceptual model of this problem. A digital model of the problem was created using computer software. This model should act as a guide to be used by policy-makers, with regards to robbery prevention strategies. The model can be used to develop and test policies before they are implemented. Therefore, it should be made possible to save much time and money in the policy-making process.

2. **WHAT WILL BE ASKED OF ME?**

If you agree to take part in this study, you will be asked to give your opinion with regards to the validity of the conceptual approach taken to develop the computer model of the study. Validity is the quality of being logically or factually correct. The time of an interview will be limited to an hour. In the case that more time is required, the researcher may request a follow-up interview with the participant. The interview will be held at a location that is most convenient to the participant (during working hours).

3. **POSSIBLE RISKS AND DISCOMFORTS**

No foreseeable risk is associated with participating in the study. The questions asked will be directed only at the validity of the conceptual approach taken for the study. The interview process will be handled in a professional manner to avoid any discomforts or inconveniences to the participant.

4. **POSSIBLE BENEFITS TO PARTICIPANTS AND/OR TO THE SOCIETY**

Participants will not benefit directly from the study. Certain benefits to society can be expected from this study. The main benefit may be a tool that will help policy-makers to make more informed choices with regards to policy development for robbery prevention. This may hopefully translate into the long-term effect of reduced robbery in the area where the tool is applied.

5. **PAYMENT FOR PARTICIPATION**

The participant will NOT receive payment and will NOT be compensated for any expenses incurred to take part in the study (e.g. compensation for transport expenses).

6. PROTECTION OF YOUR INFORMATION, CONFIDENTIALITY AND IDENTITY

Any information you share with me during this study, as well as any information that could possibly identify you as a participant will be protected. Your identity will not be shared during any stage of this study. Data will be stored on paper and/or on an electronic document such as a Word document and/or an audio recording. The data will be stored in a secure manner, so that only the principal investigator will have access to the provided data. Participants of the study will not be identified in the final research report. The information collected for this study may be used for future publications such as conference- and/or journal articles. Confidentiality and anonymity of the participant will be maintained in publications by only stating the selection criteria that the participants need to meet in order to qualify for the interview process. You as the participant will not be interviewed as a representative of the institution you work for, but rather as an expert in your own right. At the same time, no information about the institution you work for will be obtained. The name of the institution you work for will not be mentioned in the research report or any other publication relating to the collected data.

7. PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you agree to take part in this study, you may withdraw at any time without any consequence. You may also refuse to answer any questions you don't want to answer and still remain in the study. The researcher may withdraw you from this study if it seems that the participant did not answer the questions honestly.

8. RESEARCHERS' CONTACT INFORMATION

If you have any questions or concerns about this study, please feel free to contact Felix Adam [18245315@sun.ac.za; 076 568 3717] and/or the supervisor Sara Grobbelaar [ssgrobbelaar@sun.ac.za].

9. RIGHTS OF RESEARCH PARTICIPANTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research participant, contact Ms Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] at the Division for Research Development.

DECLARATION OF CONSENT BY THE PARTICIPANT

As the participant I confirm that:

- I have read the above information and it is written in a language that I am comfortable with.
- I have had a chance to ask questions and all my questions have been answered.
- All issues related to privacy, and the confidentiality and use of the information I provide, have been explained.

By signing below, I ____ agree to take part in this research study, as conducted by Felix Adam.

____ ______________________

Signature of Participant **Date**

DECLARATION BY THE PRINCIPAL INVESTIGATOR

As the **principal investigator,** I hereby declare that the information contained in this document has been thoroughly explained to the participant. I also declare that the participant has been encouraged (and has been given ample time) to ask any questions. In addition, I would like to select the following option:

	The conversation with the participant was conducted in a language in which the participant is fluent.
	The conversation with the participant was conducted with the assistance of a translator (who has signed a non-disclosure agreement), and this "Consent Form" is available to the participant in a language in which the participant is fluent.

______________________________ ______________

Signature of Principal Investigator **Date**

9.4.3 Appendix D3

Appendix D3 contains the interview guide, as approved by the REC, used to conduct semi-structured interviews with South African criminologists regarding the adequacy of the mental model presented by the causal loop diagram for project number (10190).

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Interview Guide

Robbery prevention: a system dynamics application

Department of Industrial Engineering, Health Systems Engineering and Innovation research group

This guide serves the purpose of facilitating the interview process used to validate the conceptual approach taken to develop the simulation model of the study. The dynamic hypothesis of a system dynamics simulation model can be displayed using a causal loop diagram (CLD). Figure 1 displays the CLD that serves as the conceptual model of the simulation study. Please answer the following questions after studying the diagram thoroughly. The interviewer will assist with any questions that you may have.

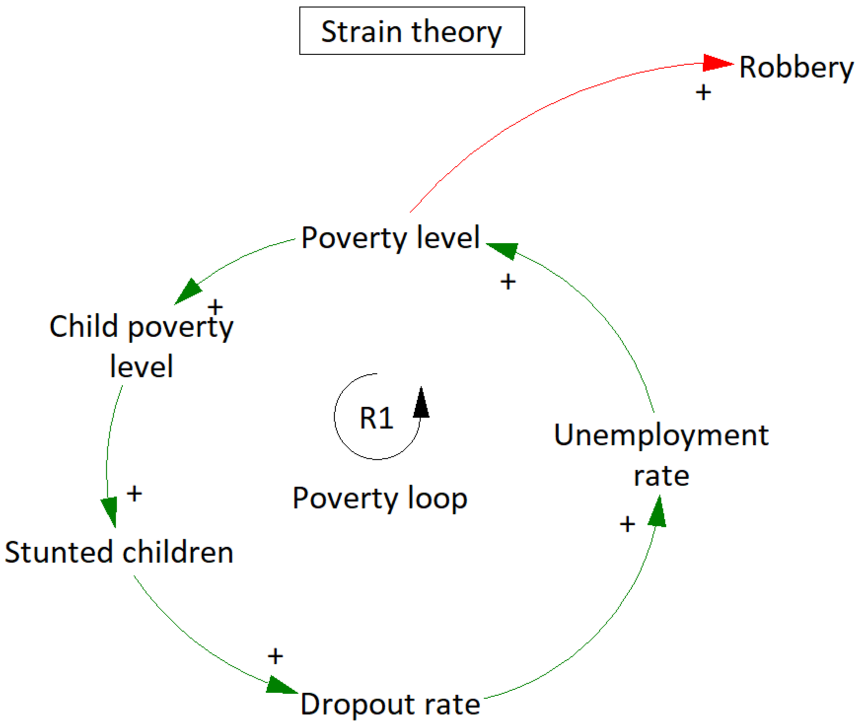

Figure 1: Causal loop diagram of the simulation study

Variable Names

1. Do you agree with the names of the variables used in the causal loop diagram?
    a. Indicate what variables you agree with and the reasoning for your agreement.
    b. Indicate what variables you disagree with and state the reason for your disagreement.

Causal Relationships

2. Do you agree that the arrows between the variables indicate causal relationships?
    a. Indicate what arrows you agree with and the reasoning for your agreement.
    b. Indicate what arrows you disagree with and state the reason for your disagreement.

Arrow Polarities

3. Do you agree with the polarities of the arrows in the diagram?
    a. Indicate what polarities you agree with and the reasoning for your agreement.
    b. Indicate what polarities you disagree with and state the reason for your disagreement.

Use of Theory

4. Do you agree with the use of theory as indicated in the diagram?
    a. Indicate what theories have been applied correctly in the diagram, explaining why.
    b. Indicate what theories have been applied incorrectly in the diagram, explaining why.

Alternative Dynamic Hypothesis

5. If applicable, please provide an alternative dynamic hypothesis that seems more appropriate than the one that was discussed in the previous questions.