# 5 Methodology and Research Design

In this chapter the methodological approach used in the study is justified and explained in section one and two. The research protocol, including data collection and analysis, is presented in section three. The chapter ends with a conceptualisation of the MIDP incentive mental model.

## 5.1 Methodological choice

### 5.1.1 MIDP incentives as a complex system problem

The choice of methodology for a research project depends, in part, on the research question(s) to be answered, the nature and extent of data availability and implicitly on how familiar the researcher is with this particular methodology. One of the problems confronting policy-makers in South Africa's automotive industry is lack of a formal policy model upon which new policy initiatives can be based. Policy intervention in the sector is often based on intuition and consensus building. Specific to the country's automotive industry, policy changes under the MIDP dispensation are often based on a comparison between industry performance and the conceived desired situation. If Government perceives the gaps between the desired and actual industry performance, it undertakes remedial measures to bridge these gaps. Sterman (2000, p.10) refers to this policy intervention approach as the event-oriented worldview (Figure 7). The approach does not acknowledge that actions often have reactions and that reactions change the policy environment in which policy decisions are being exercised. It focuses on the symptoms of the undesired outcome rather than trying to understand what could be generating the unwanted outcome.

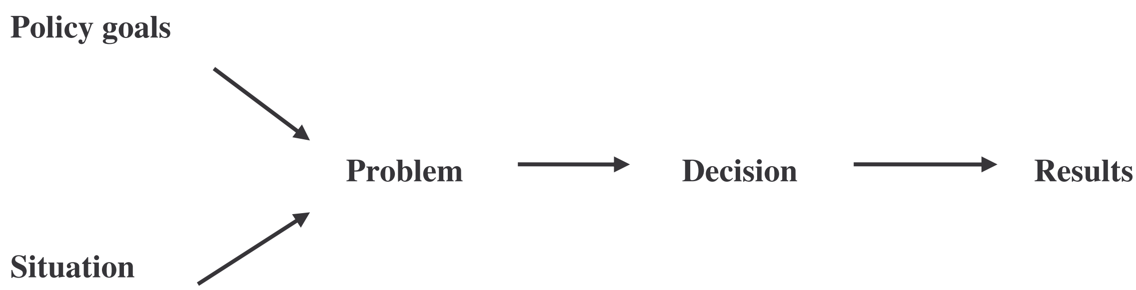


**Figure 7: Event view of the world**
(Sterman, 2000, p.10)

Though such an event-oriented view of the world can work in the short term, without understanding the cause of the undesirable performance behaviour, corrective policy intervention is almost impossible to devise. The approach increases the risk that some policy interventions may end up exacerbating the problem at hand without the knowledge of the intervener (Thomas, 1974, p.90).

It should be noted that for the MIDP, there are mechanisms in place to monitor the performance of the programme; however, it is exceedingly difficult to understand causes of unwanted outcomes under multiple and non-linear cause-effect relationships including feedbacks. Hence focus of policy discussion is often on industry outcomes. By focusing on industry outcomes, South Africa's automotive industry support model overlooks systemic interdependencies and feedback effects within the industry that have a bearing on industry behaviour. Yet, such factors have a bearing on industry performance in general. Sterman (2002, p.504) contends that the narrow event-oriented worldview is the root cause of well-intentioned efforts to solve pressing problems creating unanticipated outcomes – a phenomenon also referred to as policy resistance. Policy resistance is a central issue of concern in systems dynamics methodology and widely referred to in policy work. According to Meadows (1982, p.99) policy resistance occurs when policy intervention leads to delay, dilution, or defeat of the intended purpose. It is a tendency for intervention to be defeated by the response of the system to the intervention itself (Sterman 2000, p.3). Policy resistance often leads to the opposite of the intended results (Forrester, 1969). System dynamics singles out policy resistance as the main reason behind ineffective policy intervention. Forrester (1991) argues that as high as 98% of policies in a system have little effect on the intended systemic behaviour because of the ability of the system to compensate for changes in most policies.

The workings of the MIDP incentives demonstrate interrelationships between the automotive industry sectors and industry performance variables without explicit cause and effect. For example, vehicle assembly is linked to the domestic component sector through its supply of components to locally assembled vehicles. Increase in component manufacturing costs affect the overall cost of manufacturing of vehicles in South Africa. In terms of government incentive to the industry, import rebates to OEMs may reduce their production costs, through a downward pressure on the cost of imported OEs. On the other hand, the reduction in overall production costs of vehicles in the country may increase industry competitiveness, leading to industry growth. Some of the benefits of vehicle manufacturing may accrue to the local component sector by way of bigger markets for its products. These industry relationships are not static and independent, but are changing over time and are often non-linear and interdependent on each other. Such forward and backward relationships, changing with time, constitute a complex system. Policy design and intervention in complex situations necessitate use of special analysis tools that can capture feedback effects, non-linearities and time lags. Sterman (2000, p.5) suggests that policy interventions in complex systems require:

- Tools to elicit and represent mental models about the problem of interest
- Formal models and simulation methods to test and improve the mental model, design new policies and practise new skills
- Methods to sharpen scientific reasoning skills, improve group processes, and overcome defensive routines.

This approach is advisable due to the complexity of policy work as it cannot often be reduced to definite natural science laws and econometric models. Economic policies pursued by different countries are unique and are a function of a set of circumstances peculiar to a country and are intended to meet sets of objectives that cannot easily be reduced into functions to be optimised. Furthermore, world circumstances are always changing. Therefore, replication and generalisation of particular research findings, the two strongest arguments for most dynamic optimisation and pure econometric approaches, become less important (Sterman, 1991, p.6). Highly structured research design limits flexibility required for policy analysis and may serve only academic purposes, but not practical ones. The topic of incentives in the South African automotive industry is generating much debate; the objectives to be achieved are clear to stakeholders, but no party is sure whether the policy action being undertaken or to be implemented will achieve these objectives. If the issue was to be reduced to a dynamic optimisation function, it is likely that it will be practically impossible to get a mathematical solution for the function. Most importantly, it is likely that stakeholders will disagree on which variables must be included in the function or set of functions due to their diverse interests.

In essence, the offer of investment incentives to the South African automotive industry exhibits three distinct characteristics: Firstly, it is a feedback problem. An incentive is put in place by government; industry performance is observed and subsequently evaluated against the initial objectives. Policy action on incentives is adjusted or maintained depending on the deviation between results and initial objectives. This process constitutes a closed loop as illustrated in Figure 8 below:

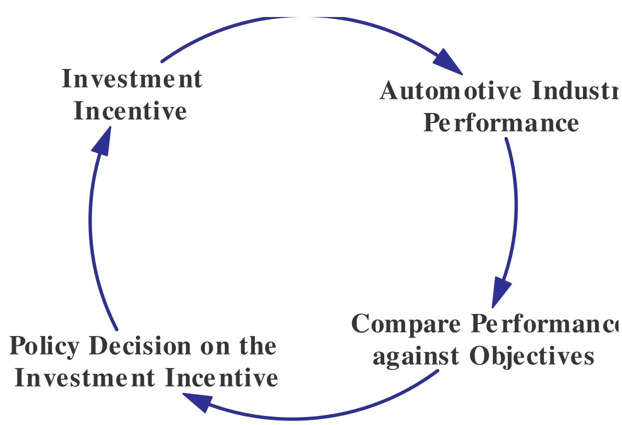


**Figure 8: Closed investment incentive loop**
(Adopted from Coyle, 1996, p.4)

Secondly, the results of the incentive are a function of systematic interactions between variables in the industry structure. There is a systematic way in which variables like investment, employment, local content use, size of domestic and international market affect each other to determine the overall performance of the industry. Thirdly, there are some broad rules that govern policy decisions within the industry that can be identified. These relate to the positive relationship between investment incentive and investment, for example. The above characteristics of the automotive investment incentive dispensation constitute a classical system dynamics problem; hence, it creates a strong basis for the use of system dynamics as a preferred methodology in answering the research question. System dynamics methodology is useful and applicable to policy problems where the dynamics have to do with the internal structure of the system (Barlas, 2002, p.1141).

The formulation of the MIDP, despite being a consultative process, put less emphasis on how incentives were to lead to industry competitiveness in the long term. As a result, processes, systemic factors and feedback effects within the industry have received little attention in the management and implementation of the programme. These factors, however, are critical in understanding industry performance. The future of the MIDP requires a re-examination of the initial thinking of the programme and a search for potential causes of unexpected industry outcomes, including systemic factors. It is critical to come up with a formal MIDP model that is cognisant of interrelationships between, and feedback effects among, industry variables and to reflect on how these systemic and process factors enrich the MIDP policy framework. System dynamics modelling often increases understanding of the problem at hand and is a basis for devising better policies (Vennix, 1996, p.3). The need to understand how industry structure is influencing the effectiveness or otherwise of incentives further reinforces the adoption of a system dynamics methodology for the research project.

## 5.2 System dynamics and system dynamics methodology

### 5.2.1 System dynamics

The system dynamics school of modelling has its own set of strict rules on what constitutes a proper professional procedure of the modelling process. The approach probably consists of a more internally consistent system of guidelines and standards than in other comparable schools of modelling (Randers, 1980a, p. xvi). Although models, in general should have a number of desirable attributes, each modelling approach tends to emphasise some, but not all. System dynamics as a unique modelling methodology is strong in increasing understanding of the observed phenomenon, and in establishing consequences of different options available at a decision point (Randers, 1980a, p.xvii). The system dynamics approach is inclined towards refutationism. Refutationism as a way of thinking in the knowledge acquisition debate holds that scientific knowledge consists of conjectures that are refutable, vulnerable to empirical error and that knowledge advancement is achieved through the process of adjusting, or change of mistaken conjectures to overcome refutations (Bell & Bell, 1980, p.4). The refutationism approach puts more weight on the thinking process than on data per se. In line with refutationism, the system dynamics field suggests that the first stage of generating knowledge is to think about the issue at hand. The refutation method requires the search for causal explanations, which in turn opens up the opportunity for objective interrogation of the presupposed causal relationships, and in the process new knowledge is created.

Although sometimes interchangeably used, system dynamics (SD) as a field of study and as a methodology are two different things. The system dynamics field deals with the study of and the managing of complex feedback systems, such as one finds in business and other social systems. In the SD field, system has a specific meaning related to the feedback effect:

> *"While the word system has been applied to all sorts of situations, feedback is the differentiating descriptor here. Feedback refers to the situation of X affecting Y and Y in turn affecting X perhaps through a chain of causes and effects. One cannot study the link between X and Y and, independently, the link between Y and X and predict how the system will behave",* (System Dynamics Society web page, www.systemdynamics .org).

System dynamics as a methodology is grounded in control theory and modern theory of nonlinear dynamics. System dynamics is also a practical tool that policy makers can use to help solve important problems (Sterman, 2002, p.503). System dynamics provides a means by which to capture complex relationships and feedback effects within a set of interrelated activities and processes (Vennix, 1996, p.21). Its presentation has a user-friendly interface that encourages non-academics to internalise the logic behind the model. In addition, the approach allows the use of quantitative and qualitative data; hence, it is not limited in its use when quantitative data is unavailable. Specialised software in system dynamics modelling allows scenario simulations, in fairly easy and understandable steps, an aspect critically important in applied research.

### 5.2.2 Principles of system dynamics methodology

The purpose of SD study is to understand causes of dynamic problems and search for high leverage policy interventions to alleviate them. According to Barlas (2002, p.1134), the SD approach is based on the following principles:

1. The existence of causal relations rather than mere statistical correlation: SD aims at understanding the underlying cause of dynamics behaviour rather than correlation or forecasting.
2. The adopted causal relationships are based on a "ceteris paribus" assumption despite the notion of causality being a debatable notion.
3. The time element should always be acknowledged. Over time, circular causality takes place, creating feedback effects. Without factoring in the time element some feedback effects will be suppressed. The relationship between population and birth rate, for example can be taken to be one-way and static. Over time, however, it changes to a dynamic feedback problem as birth rate begins to affect population. Often, there are intervening factors between the two variables under consideration for a feedback loop to form.
4. Dynamics behaviour pattern orientation: The problems of focus for SD modelling should be characterised by undesirable performance patterns rather than isolated events. It is recognised that events cannot be understood in isolation from their past dynamics. The goal of an SD project is therefore to construct a hypothesis that explains why and how the dynamic pattern of concern is generated.
5. Endogenous perspective: The internal structure should be the main cause of dynamic behaviour of concern.

6. Systems perspective: The dynamics of the variables must be closely associated with the operation of the internal structure of a system. The term 'system' is used holistically to refer to a collection of interrelated elements that constitute a meaningful whole. Elements within a system should be able to interact in a meaningful way to serve a purpose or to play a particular recognisable role. Coyle (1996, p.4) refers to a system as a collection of parts organised for a purpose. It follows that the model boundary should be wide enough to have an internal structure rich enough to provide an endogenous account of the dynamics of concern. The underlying philosophy of the endogenous approach is that even if there could be some external influence, the problematic behaviour arises because the internal structure of the system cannot appropriately cope with the external influence.

### 5.2.3 System dynamics modelling methodology and tools

System dynamics methodology is a method by which one can model process structures and analyse their behaviour through the investigation of how resources flow, accumulate and interact in a system over time in dynamic interdependent feedback loops (Vanderminden, 2006, p.17). A system dynamics approach deals with problems that are dynamic in nature i.e. changing over time and are associated with the internal structure of an identifiable system. The endogenous characterisation of problems under the system dynamics approach points to the fact that policy makers can influence systems to behave in desirable ways. As a means of investigating systemic dynamic feedback problems, system dynamic methodology builds models of selected aspects of a system to study specific behaviour.

SD methodology takes cognisance that the fact that most of the information needed to understand and later on devise solutions to a problematic situation lies in knowledge and assumptions embedded in the minds of those who are active participants in the problematic situation. The specific set of information and assumptions in people's minds about an aspect of interest is referred to as a mental model. Caulfield and Maj (2002, p.26) define a mental model as an enduring and accessible, but limited, internal conceptual representation of an external system whose structure maintains the perceived structure of that system; it is a filter through which we interpret experiences, evaluate plans, and choose among possible courses of action (Sterman, 2000, p.16). A mental model contains ideas, opinions, assumptions, generalisations, with respect to a policy problem and related issues (Vennix, 1990, p.16). It describes facts and concepts that constitute one's understanding of a particular phenomenon (Sterman, 1991, p.210). Mental models are the starting point of formal system dynamics modelling and the modelling process brings to the surface mental models driving a particular system (Caulfield & Maj, 2002, p.26)

System dynamics uses two main tools in the modelling process, causal loop diagrams and stocks and flow.

#### 5.2.3.1 Causal loop diagrams

Causal loop diagrams are a pictorial depiction of the relationships of a systemic situation of concern. The diagrams are referred to as 'causal' because their first objective is to capture the causal relationships between variables and 'loops' because they also capture feedback effects among the variables under study. Feedback is one of the core concepts of system dynamics, yet a mental model seldom takes into cognisance feedbacks while determining dynamics of a system (Sterman, 2000, p.137). Casual diagrams provide an important means of capturing feedbacks in a system and make such effects explicit.

A standard form of presenting causal relationship is by using arrows and signs at the end of the arrows. The arrow presents a cause-effect relationship between the two variables connected. The interpretation is that the variable at the tail of the arrow has a causal effect on the variable at the arrowhead. The sign at the arrowhead specifies the nature of the causal effect, holding other factors constant. The '+' shows that the two variables move in the same direction when the causing variable changes. The '-' shows that the two related variables will move in opposite directions when the causing variable changes (Richardson, 1997, p.249). For example, the causal relationship between the price of a product and its demand will be depicted by an arrow from the price of the product to the demand of the product with a negative sign at the arrow end. This causal relationship, interpreted as the increase in the price of product, will cause the demand of the product to decrease, holding other factors constant.

Although loops often consist of a number of causal relationships, they take a unique sign - either positive (self-reinforcing) or negative (self-correction). The sign of the loops is also referred to a loop polarity or identifier. It is indicative of the overall effect of the feedback process. Reinforcing loops tend to amplify whatever is happening in the system, while self-correction loops tend to counteract and oppose change (Sterman, 2000, p.12; Richardson, 1997, p.248). Caution should, however, be taken in interpreting the polarity of a loop vis-à-vis what happens in reality. Polarity of casual loops describes what happens if there was to be a change in one of the related variables under consideration, holding other factors constant. Polarity may not necessarily describe what actually happens in reality. Sterman (2000, p.139) cautions that what actually happens is a function of the combined effect of other affecting factors that are held constant in deciding on the loop polarity. Also if the variables under consideration happen to be flows and stocks, without the explicit information on the rates of change, one cannot be sure that a positive change in the flow will indeed cause the stock to move in the same direction. Again, one has to keep in mind that correlation does not constitute causality. However high the $R^2$ value between variables and however significant the coefficients of a regression could be, due care should be taken before interpreting a relationship as causal (Sterman, 2000, p.142). A good example to illustrate this point is related to the frequency of car accidents during the rainy season due to slippery roads and the purchase of warm clothes. The incidence of road accident data is likely to have a high positive correlation with warm clothes purchases. If one was to interpret this relationship as causal, it may lead to an erroneous recommendation to reduce the purchase of warm clothes during the rainy season in order to reduce accidents. A summary of notes on causal loop symbols are presented in Figure 9.

**Notes on the causal loop diagrams:**

- → The arrows denote a cause-effect relationship between the connected variables
- "+" at the head of the arrow denotes that the connected variables change in the same direction, i.e., when one variable increases, the other variable will also increase and vice versa.
- "-" at the head of the arrow denotes that the connected variables change in opposite directions. When one variable increases, the other will decrease and vice versa.
- (+) denotes an overall reinforcing effect
- (−) denotes an overall tendency towards an equilibrium

**Figure 9: Description of causal loop symbols**

### 5.2.3.2 Stocks and flows

Another important tool in system dynamics modelling critical in quantitative modelling is the presentation of variables in the form of stocks and flows. This requires that the two types of variables be correctly distinguished. Stocks refer to accumulations over time. Stocks represent conditions within a system at any particular time of reference. Flows, on the other hand, represent the rate of change of stocks in the system. They are a set of activities that cause conditions to change (Barlas, 2002, p.1144; Richmond, 2004, p.15). Whereas stock tells you the state of affairs in a system, flow informs on how things are going (Richmond, 2004, p.35). Flows do not have an impact on stocks but rather fill or drain the stock. When you freeze time, stocks remain while the flows cease to exist. Hence, population is a stock but death and birth are flows.

In diagrammatic form, stocks are presented as a rectangle while flows are presented as arrows with a 'tap' to signify that the flow can be regulated. Flows can be uni- or bi-flows. Uni flows flow in one direction while in the latter the flow can be either way. Clouds represent the sources and sinks for the flow (Figure 10). "A source represents the stock from which a flow originating outside the model boundary arises, sinks represent the stocks into which flows leaving the model boundary drain" Sterman (2000, p.192).

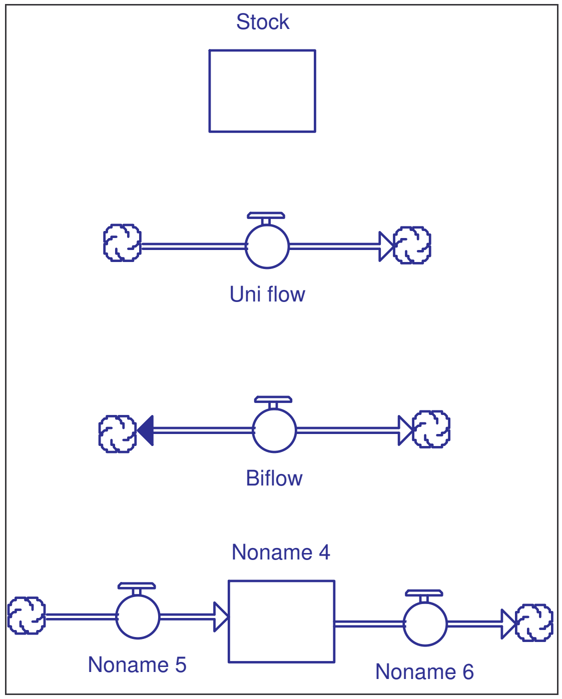


**Figure 10: Generic presentation of stocks and flow diagrams**

> *"Stocks play a central role in dynamics feedback management problems. Their control is often the primary responsibility of managers … Yet controlling stocks is subtle and dynamically complex by their nature"* Barlas, 2002, p.1146.

Using causal loop diagrams to capture systemic relationship, system dynamicists are able to develop qualitative models that provide insight on how the internal working of a particular system is influencing performance. Although some authors claim that qualitative modelling, using causal loops, should be treated just as the first step of the modelling process, its value in terms of making explicit the logic of intervention in complex problematic situations is not contestable.

Stocks and flow allows quantification of SD models and subsequent scenario simulations. Whereas qualitative modelling is informative on the general logic of intervention, the "what if" questions of complex situations can only be answered through quantitative modelling, using stocks and flows.

### 5.2.4 Steps in system dynamics modelling

There is a consensus on system dynamics modelling stages. The few differences noticeable among authors are more on the demarcation of the stages. A comprehensive comparison of how different authors present the modelling process was presented by Luna-Reyes & Anderson (2003, p.275). They point out that “although the ways of grouping the activities vary among the different authors, the activities considered along the different stages remain fairly constant across them, allowing the building of a comparison”. The comparison table of states of SD modelling among major authors on the subject is presented in Table 17.

<table>
<tr><th>Randers (1980b)</th><th>Richardson and Pugh (1981)</th><th>Roberts et al (1983)</th><th>Wolstenholme (1990)</th><th>Sterman (2000)</th></tr>
<tr><td rowspan="2">Conceptualisation</td><td>Problem definition</td><td>Problem definition</td><td rowspan="2">Diagram construction and analysis</td><td>Problem articulation</td></tr>
<tr><td>System conceptualisation</td><td>System conceptualisation</td><td>Dynamic hypothesis</td></tr>
<tr><td>Formulation</td><td>Model formulation</td><td>Model presentation</td><td rowspan="3">Simulation (stage 1)</td><td>Formulation</td></tr>
<tr><td rowspan="2">Testing</td><td>Analysis of model behaviour</td><td>Model behaviour</td><td rowspan="2">Testing</td></tr>
<tr><td>Model evaluation</td><td>Model evaluation</td></tr>
<tr><td rowspan="2">Implementation</td><td>Policy analysis</td><td rowspan="2">Policy analysis and model use</td><td rowspan="2">Simulation (stage 2)</td><td rowspan="2">Policy formulation and evaluation</td></tr>
<tr><td>Model use</td></tr>
</table>

**Table 17: System dynamics modelling process in classic literature**
(Luna-Reyes & Anderson, 2003, p.275)

The modelling process in this study was tailored along the steps described by Barlas (2002). According to Barlas (2002, p.1147) the modelling process in system dynamics follows five distinctive steps:

1. Problem articulation (boundary selection): This involves clarifying the problem to be solved and ascertaining what important variables should be included in the model. Emphasis should be put on coming up with a simple model that captures the most important systemic factors. The usefulness of any model often lies in simplifying reality to a level comprehensible to the mind. Other issues to be considered at this level are the reference mode – sets of graphs and data showing the development of the problem over time and proper selection of time horizons.

2. Dynamic hypothesis: The hypothesis is dynamic because it must provide an explanation of the problem in terms of time (how it has developed over time and probably how it is likely to unfold in future). A dynamic systems hypothesis is a working theory of how the problem arose.
3. Formal formulation of a simulation model: Once the problem has been well articulated, an initial dynamic hypothesis formulated, model boundary defined, and a conceptual framework is in place, the next stage is to formulate a simulation - formal model.
4. Testing the model: This involves comparing simulated behaviour with the real world. Testing models using extreme conditions provides an easy way to find out whether the model makes sense.
5. Policy formulation and evaluation: Policy evaluation will involve the changing of parameters, strategies, structures, and decision rules to come up with a more desirable system arrangement.

## 5.3 Data collection

The system dynamics modelling process makes use of quantitative and qualitative data. Three data types are needed to develop the structure and decision rules of SD models: numerical, written and mental data (Forrester, 1980, p.555). Numeric data takes the form of time series and cross section databases; written data ranges from organisation operation documents and archive documents to minutes of meetings; mental data includes all the information embedded in people's minds i.e. their understanding of how a system of interest works and how decisions are actually made.

### 5.3.1 Research location

The research was located within the Government Programmes Department of the Automotive Industry Development Centre (AIDC). The AIDC is a government established but autonomous company that was mandated to assist the South African automotive industry attain global competitiveness. The AIDC works in partnership with business, government departments and other organisations to invigorate economic growth via the automotive industry. At the time of data gathering, the AIDC Government Programmes Department supported government administration of the PAA and was the secretariat for the Motor Industry Development Council. The Government Programmes Department provided a centre for data collection on information pertaining to the performance of the automotive industry as it related to the MIDP. As far as PAA administration was concerned, the Government Programmes Department was responsible for receiving PAA applications from vehicle assemblers and component manufacturers. The department evaluated the applications and thereafter recommended to the International Trade Administrative Commission (ITAC) division of the Department of Trade and Industry (thedti) for the release of rebate certificates. The department received progress reports and business plan deviations on PAA benefiting projects, before it recommended the release of subsequent rebate certificates. The AIDC in general and the Government Programmes Department in particular provided an ideal location for relevant data collection, subject to confidentiality restrictions.

### 5.3.2 Secondary data

The research population of the study consisted of all vehicle and component manufacturing companies that constituted the South African automotive industry. In 2005, there were eight vehicle manufacturers and some 278 first-tier component manufacturers in the country.

Quantitative historical data was collected from thedti and the National Association of Automotive Manufacturers of South Africa (NAAMSA).

Thedti carries out annual surveys to capture industry performance data as part of its monitoring mandate. Although part of this data is confidential, data relating to general trends in industry performance is published in the department's annual publication "Current developments in the automotive industry" and is available in the public domain. Thedti data is triangulated with other internal but confidential data sources, thereby increasing its reliability. Since the researcher was not directly involved in the drafting of the questionnaire sent to industry, an independent assessment of the questionnaire was done to establish the extent to which the elicited data was appropriate to the research question. As the data sought was on industry performance, there was little ambiguity on interpretation of the questionnaire. As such, even if the researcher had prepared the questionnaire, it would not have been significantly different on questions relating to industry performance. One issue of concern on thedti data is its representativeness of the industry. Response to the industry survey questionnaire is voluntary; therefore, the sample size is self-selected. Depending on the number of companies that respond to the survey, thedti data may not be representative of the industry. A review of the 2006 annual survey, however, revealed that the sample size, for vehicle manufacturing, from which data was captured, was indeed representative of the industry. Questionnaires were sent to all eight local vehicle manufacturers in the country; all of them responded. Forty questionnaires were sent to the component sector of some 278 first-tier suppliers, and half of the companies responded.

NAAMSA is the national association of all domestically based light, medium and heavy commercial vehicle manufacturers. NAAMSA is also the representative organisation for franchise holders marketing vehicles in South Africa.  NAAMSA membership stood at 25 companies at the beginning of 2006. The association collects performance data from all its members. The data is published in the organisation's annual reports and is periodically disseminated to the public through press briefings. NAAMSA data was compared with thedti data and in cases of significant deviation between the two data sets, thedti data was preferred.

Industry performance data for estimation of model parameters and rates of change was compiled using thedti and NAAMSA data sets. A summary of industry performance data for South Africa is presented in Table 18.

| Year | OEM Investment (R mil)[1] | Production (R mil) | Domestic vehicle market (R mil) | Exports (R mil) | Imports (R mil) | Rebatable Imports (IRCC and PAA) R mil |
|---|---|---|---|---|---|---|
| 1990 | 660 | 13,636 | 19,584 | 800 | 6,300 | |
| 1991 | 697 | 12,800 | 19,379 | 1,100 | 6,300 | |
| 1992 | 858 | 12,238 | 19,206 | 1,500 | 6,600 | |
| 1993 | 400 | 14,409 | 21,677 | 2,300 | 9,100 | |
| 1994 | 492 | 15,638 | 23,705 | 2,800 | 12,000 | |
| 1995 | 847 | 22,236 | 33,633 | 4,200 | 16,400 | 4,800 |
| 1996 | 1,171 | 25,079 | 39,896 | 5,100 | 19,200 | 5200 |
| 1997 | 1,265 | 29,606 | 38,852 | 6,600 | 17,200 | 5,851 |
| 1998 | 1,342 | 25,306 | 36,359 | 10,100 | 19,900 | 7,415 |
| 1999 | 1,511 | 27,847 | 35,146 | 14,800 | 22,800 | 12,445 |
| 2000 | 1,562 | 38,872 | 40,593 | 20,000 | 29,700 | 17,761 |
| 2001 | 2,078 | 42,815 | 46,895 | 30,000 | 38,000 | 21,622 |
| 2002 | 2,726 | 55,602 | 46,928 | 40,100 | 50,200 | 27,307 |
| 2003 | 2,325 | 64,744 | 52,236 | 40,700 | 49,800 | 30,416 |
| 2004 | 2,220 | 71,833 | 66,353 | 39,200 | 58,000 | 28,938 |
| 2005 | 3,576 | 82,595 | 84,982 | 45,000 | 72,000 | 28,968 |

**Table 18: South's automotive industry performance 1990 - 2005**

**Note**: Value of rebatable imports calculated based on estimated PAA qualifying investment and the value of export performance

(NAAMSA, 2001/2006)

Literature on system dynamics modelling does not provide foolproof methods of determining which variables are important in understanding a problematic situation and the nature of causal effect among them. Some SD practitioners have adopted statistical means in ascertaining which variables should be included in particular models and to establish possible cause and effects. The statistical approach is criticised for being too mechanical and abstract to capture complex relationships often dealt with in systems dynamics modelling. There seems to be a general agreement that qualitative data, expert opinion and informed judgment are the best tools for determining variables for inclusion in the model.

> *"During the mid-1970s and early 1980s several system dynamicists undertook studies aimed at determining whether or not econometric techniques could be used to accurately estimate the parameters of a system dynamics model……Results of these studies showed overwhelmingly that under almost all but perfect circumstances, the econometric techniques were unable to accurately recover the model's parameter values",* Radzicki, 2004, p.6.

What is not well explored is the way in which statistical techniques can complement intuition and expert opinion and vice versa in the choice of model variables. For example, whereas SD modelling deals with causal relationships and not correlation, establishing correlation could be the first step towards the qualification of a causal relationship. In other words, correlation is a necessary but not a sufficient condition for a causal relationship. As such, correlation analysis can be used as an elimination method for hypothesised relationships and thereafter qualitative analysis and intuition can be used to confirm or refute causal relationships among those variables that are correlated. In this respect, a correlation analysis of quantitative data was done to ascertain that there was a potential causal effect among the identified key industry performance variables. Table 19 shows the correlation we intended to establish before applying qualitative data and expert opinion to assume causal relationships.

| **Independent variable** | **Dependent variable** |
|---|---|
| Value of rebatable imports (IRCC) | Investment |
| Value of rebatable imports (IRCC) | Imports |
| Value of rebatable imports (IRCC) | Production |
| Market size | Investment |
| Market size | Imports |
| Market size | Production |
| Market size and Value of rebatable imports (IRCC) | Investment |
| Market size and Value of rebatable imports (IRCC) | Imports |
| Market size and Value of rebatable imports (IRCC) | Production |
| Production | Exports |
| Production | Employment |
| Market size | Production |

**Table 19: Hypothesised relation among industry performance variables**

Apart from the relationship between rebatable imports and domestic market, the Pearson correlation coefficients for the above-hypothesised relationships were above 0.5 at a 95% confidence interval. A matrix of correlation coefficients of industry variables relevant to the MIDP incentive model is presented in Table 20.

| Independent variable | Dependent variable | Pearson correlation coefficient | Significance level |
|---|---|---|---|
| Value of rebatable imports | Investment | 0.87837 | 0.0004 |
| Value of rebatable imports | Imports | 0.93429 | 0.0001 |
| Value of rebatable imports | Production | 0.92862 | 0.0001 |
| Value of rebatable imports | Market size | 0.85359 | 0.0008 |
| Market size | Investment | 0.93365 | 0.0001 |
| Market size | Imports | 0.98056 | 0.0001 |
| Market size | Production | 0.98934 | 0.0001 |
| Production | Exports | 0.96688 | 0.0001 |

**Table 20: Correlation between automotive industry variables**

By implication, since there is a strong correlation between market size and rebatable imports, and each of these variables is individually correlated to investment, it can be deduced that there is a correlation between market size and rebatable imports taken together with investment. The same logic can be extended to the joint correlation between market size and rebatable imports vis-à-vis imports and production. The industry wide correlation and regression analysis of industry performance is included as Appendix 1. Meeting the correlation criteria meant that one could then subject the relationship to qualitative and intuitive rigour to establish causal effect before inclusion in the formal model.

### 5.3.3 Primary qualitative data

Although numerical and written data could be accessed from thedti databases and ITAC archive documents, subject to confidentiality, the biggest challenge was to access the qualitative mental data. Developing an MIDP incentive model required specific understanding of the intentions of the programme promoters and the assumptions underlying the dispensation. Such data was not explicit in the numerical and written data sources. The research had to come up with creative means to tap into information in stakeholders' minds.

It is widely acknowledged by a number of leading authors on the subject that the most important data required to build a system dynamics model is often qualitative (Luna-Reyes & Anderson, 2003, p.274). Articulation of problematic situations from a system dynamics perspective requires the use of qualitative data. Specific to policy work, subsequent formulation of a dynamics hypothesis and formulation of a qualitative model requires insight into the mental models of role players (Sterman, 2000, p.16; Luna-Reyes & Anderson, p.275). Key variables underlying behaviour of interest resides in the mental database of some of the actors (Richardson and Pugh, 1981, p.19). More often, mental data cannot be accessed directly but must be elicited through interviews, observation and other methods (Sterman, 2000, p.853). The researcher usually needs to interact with people involved in the problematic situation over and above the use of archival research, data collection, interviews and direct observation or participation (Sterman, 2000, p.90). Qualitative data is also useful at the model formalisation stage. It assists in the choice of which variables and structures are important in influencing the reference models and subsequently crucial in answering the research question. Sterman (2000, p.854) cautions that "omitting structures or variables known to be important because of numerical data are unavailable is actually less scientific and less accurate than using your best judgment to estimate their values".

Quantitative data to support the model building process was collected using two collection techniques: participant observation and discourse analysis. In participant observation, the researcher interacts with the study situation. Standard collection instruments are a notebook and a collection of documents being discussed by the group. Data collected through participant observation can be paired with interview collection in order to unearth individual motivations or behaviour that may not be obvious (Luna-Reyes & Anderson, 2003, p.283).

Discourse analysis, on the other hand, is a qualitative data collection technique whereby one studies interaction of people in the context they occur naturally. The technique often goes hand in hand with and supplements participant observation. From data gathered from participant observation, the researcher selects the pieces of the text related to the problem under scrutiny, followed by a commentary that is a reflection of the wisdom and understanding that the specific text adds to the research effort (Bernard, 1999, p.442). In system dynamics modelling, the text should be describing behaviour over time for a specific variable or a causal structure inside the group's mental model. Qualitative data collection and analysis, when done properly, always bring formality and rigour into the modelling process (Luna-Reyes & Anderson, 2003, p.284).

The uncertainty and complexity of policies can overwhelm a single mind, as policy making is often a group exercise. The researcher had to be aware of the difference in perceptions and expertise of group members. Identifying positions on which there is consensus is one way to control for perception and expertise bias. It is consensus, not compromise, that is a vital element of policy formulation (Vennix 1996, p.5; Hines and House, 2001, p.14), but consensus has to be reached in an objective way. Post-meeting unstructured interviews were also held with contributing representatives to clarify positions upon which there was no consensus at the meeting. The intention was to ascertain that the meeting understood what the participant was trying to convey. This was another means to control communication gaps. It was recognised that there was a risk that members would be emotionally involved with a particular aspect of discussion and hence not reveal objectively what they thought (Collins & Bloom, 1991, p.28-29). The post-meeting interviews were aimed at further mitigating this bias.

In all, the researcher attended 17 MIDC meetings stretching over a period of 30 months (Appendix 2). A digital voice recorder was used to record these meetings. Information was later transcribed according to the following themes relating to the key steps of SD modelling:

1. Research problem identification/ establishment of the reference mode: The intention here was to confirm the problematic situation on which the research problem was based.
2. Working of the PAA: This related to incentive performance in a dynamic environment.
3. Causal effects within the industry: Although not explicitly expressed, special care was taken to capture the causal relationships within the industry, in particular those related to the reference mode. These had to be agreed upon by all stakeholders.

4. Systemic aspects: Under this theme, the researcher was looking for information to validate feedback effects within the industry under the MIDP incentive dispensation.
5. Data issues: Since quantitative data was often available for analysis, under this theme information regarding its completeness, relevancy and shortfalls in relation to the research question was captured.

The qualitative data emanating from the interactions and participation at the MIDC meeting was confidential as such could not be included as part of the study report. It should be noted, however, that in capturing the qualitative data, care was taken to ensure that the views captured were those on which all stakeholders agreed. Given the diversity of interests at the MIDC forums, special care was taken to avoid sector bias and non-agreed upon positions. Consensus is an important issue when it comes to soliciting information from people holding different views (Vennix, 1996, p.2). It is acknowledged that the sample used was self-selected as per the composition of the MIDC and as such its representativeness could be questioned. The nature of MIDC composition, however, ensured that all key stakeholders were represented for it to have a quorum. To a large extent, the MIDC constituted a representative stratified industry sample.

### 5.3.3 Expert opinion

Apart from the qualitative information that was accessed through the attendance of MIDC meetings, expert opinion was sought from three experts on MIDP incentives. The choice of the experts was a subjective exercise guided by the roles they played in the initial formulation and implementation of the programme, and expertise in system dynamics modelling.

Of all government officials that were involved in the formulation of the MIDP, only two were still employed by thedti. These specifically were selected for interviewing. Unstructured interviews were arranged with them to provide an insight into what motivated the start of the programme and its expectations. Details of the interviewees and dates of the interviews are provided in Appendix 3. Due to the good working relationships created and as the researcher became more familiar with the working of the incentives, the officials offered ongoing clarification on their initial insights. These insights from the people who were involved in the formulation of the MIDP were particularly important in the establishment of a mental model of industry incentives.

The implementation of the PAA had been outsourced to the Automotive Industry Development Centre (AIDC) Governments Department. The researcher was positioned in the same department as part of the PhD Internship. This allowed him to have in depth understanding into the practical administration of the incentive. It also exposed him to data pertaining to the actual performance of the incentive although much of which was confidential and could only be referred to for comparative purposes. Ongoing involvement with the administration of the PAA and interaction with other staff in the department enabled the researcher put into context, issues pertaining to the PAA incentive and how it related to the rest of the MIDP incentives and helped him to identify linkages within the industry, an aspect that had not been explicitly expressed by the governmental officials.

The modelling process also benefited from the input of a system dynamics modelling expert. An expert in system dynamics modelling was approached to advise on the formal model from a technical point of view. In the process, the model structure was validated to a reasonable extent.

## 5.4 Qualitative conceptualisation of MIDP Incentives model

### 5.4.1 Establishment of the reference mode

Using both qualitative and quantitative historical data, a reference mode for the research problem was established. The reference mode is the time development of an aspect of interest (Randers, 1980b, p.121). In this study, it was the trend in the industry trade balance after the commencement of the MIDP. The industry trade deficit had been increasing at a significant rate since the inception of the MIDP (Figure 11). The trade deficit trend simulated by the model did not fit actual trade balance well in the first 4 years of the MIDP.

This exception was acceptable; given the time frame for the simulation and that on the whole the simulated trend matched actual trade balance trend.

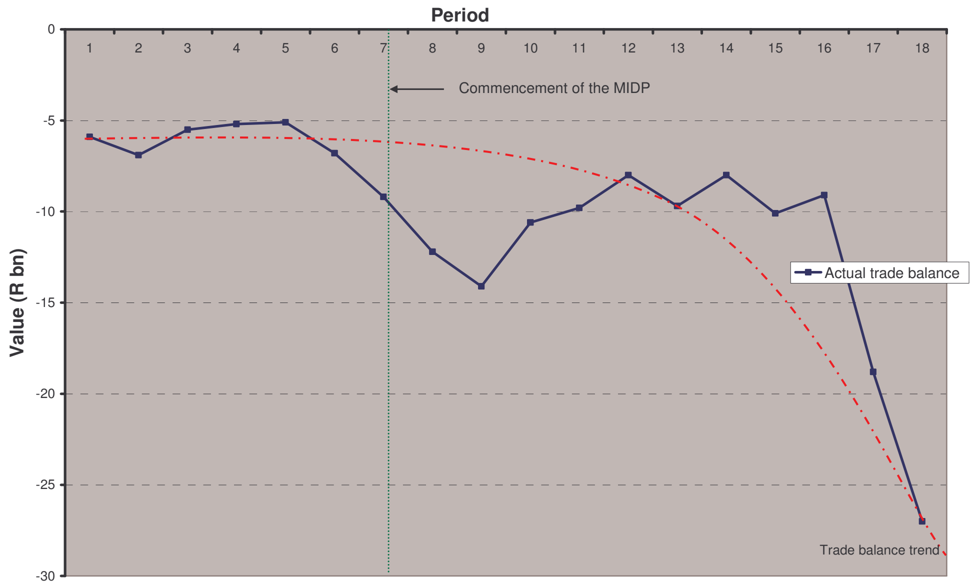


**Figure 11: Reference mode for the study of the increasing trade deficit of the South's automotive industry (Period in years)**

After establishment of the reference mode, the next step was to develop a model that was capable of reproducing the behaviour of the reference mode. The reference mode helped to keep the model simple and transparent by guiding the discerning process of variables that may not be so useful in explaining the mode. Hence, the focus of the study became oriented towards answering the question of what were the basic causes of the reference mode behaviour (Randers, 1980b, p.123).

### 5.4.2 Dynamic hypothesis

Since the only way the industry could benefit from the MIDP incentives was to offset duties payable on imports, MIDP incentives encouraged industry imports. This occurred without a commensurate increase in exports. The incentives were, thus responsible, in part, for the increasing industry trade deficit. By implication, industry success in the long term would be jeopardised by the increasing industry trade deficit potential to crowd out domestic production. The reference mode and the basic mechanism of the study constituted the dynamics hypothesis of the study (Randers, 1980b, p.126).

The formalisation process of the MIDP incentive model took advantage of the knowledge of MIDC constituent members, forum policy documents to which the researcher was exposed to when attending MIDC meetings, as well as archive data. As noted by Randers (1980b, p.129):

> *"Most human knowledge takes a descriptive non-quantitative form, and is contained in the experience of those familiar with the system, in documentation of the current conditions, in descriptions of historical performance, and in artefacts of the system"*

### 5.4.3 Model conceptualisation

The goal of the conceptualisation stage is to arrive at a rough model capable of addressing the relevant problem and for the formulation stage; it is to check that the basic mechanism is included in the conceptual model and that this conceptual model can reproduce the reference mode (Randers, 1980b, p.130). From an SD perspective, the automotive industry in South Africa can be seen as a system; that is, a group of independent but interrelated elements comprising a unified whole. The conceptualization of the PAA SD model started with capturing the static mental model of the MIDP incentives in general.

#### 5.4.3.1 Motor Industry Development Programme mental model

The MIDP policy framework is guided by a uni-directional, static and non-interactive mental model. The model presupposes that providing the automotive industry with export and investment allowances to import automotive products in the country free of duty can influence industry competitiveness and the general economy positively. Companies use rebates to offset import duty payable on vehicles and automotive components in excess of the duty-free allowance. Figure 12 captures the interpretation of the thinking behind the MIDP design.

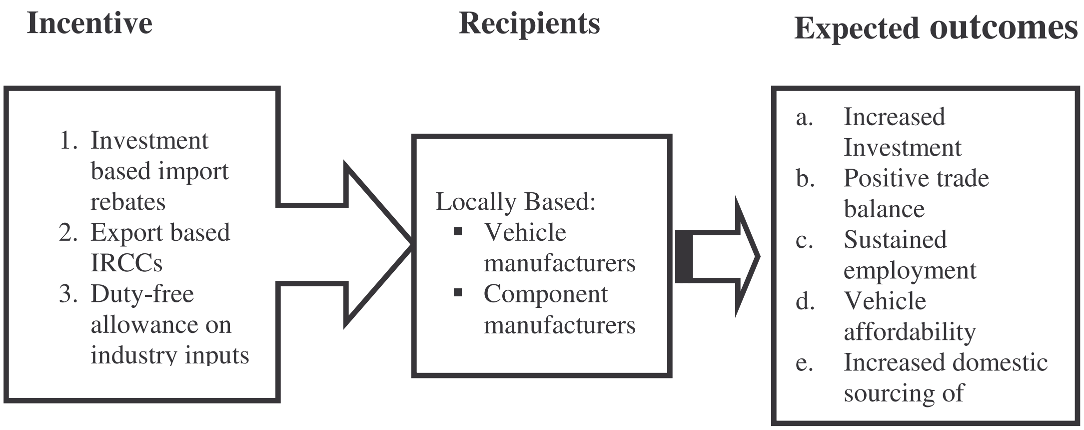


**Figure 12: Static uni-directional MIDP incentive model**

The MIDP mental model presented in Figure 12 reveals two conspicuous shortcomings from a systems dynamics perspective:

- It does not capture feedback effects between the model variables. The model assumes, for example, a positive relationship between the value of rebates earned and industry production levels, without taking into account that production levels may in turn affect the value of IRCCs through the export variable. Increase in production has a positive effect on export levels through low average cost realisation, and subsequently on the value of export-based IRCCs.
- The model assumes that MIDP objectives as captured by the expected outcomes matrix have no effect on each other. Possible trade-offs and complementations between programme outcomes seem to be acknowledged but not understood because of the complexity pertaining to the overall incentives offer.

The thinking behind the MIDP reveals gaps in capturing systemic relationships, processes and feedback effects active within the industry. Ignoring such feedback and variable interrelationships in the model leads to inaccurate and incomplete perceptions of factors underlying a particular policy and leads to ineffective policy intervention. In order to get a better insight into the effects of government support to the motor industry, these aspects have to be incorporated in the MIDP mental model.

## 5.5 Synthesis

The MIDP may appear to be a simple concept, but its ramifications on industry dynamics are vast. The working of the MIDP shows interrelationships between sectors and industry variables without explicit cause and effect characteristic of a complex system. Under the programme, Government uses two policy tools to influence industry performance – the stock of import rebates and the level of duty-free imports allowable. After specifying rules governing the policy tools, what transpires within the industry and the subsequent performance are largely dependent on triggered industry dynamics, which in turn depend on industry structure. To have an insight into the likely outcomes of government intervention, one has to understand the structure of the dynamics at play within the industry. A qualitative system dynamics model provides a useful starting point in this regard.

In the next chapter, a formalisation of the PAA and the IEC arrangement into a qualitative system dynamics model using high-level Casual Loop Diagrams (CLDs) is done. The CLDs capture some of the systemic factors that are omitted by presenting the MIDP as a uni-directional, static and non-interactive model. This is followed by quantitative formalisation of the incentive model using stock and flow diagrams. The model boundary was set to include those industry variables that have a direct relationship with investment and exports, on one hand, and also have a bearing on the industry trade balance as the reference mode.

# 6 Formalisation of the Productive Asset Allowance of the South African automotive industry using a system dynamics approach

## 6.1 Introduction

For many late-developing countries wishing to build up domestic manufacturing capacity, the question is no longer whether to give or not to give industry incentives, but of how to structure such incentives to serve national interests. The automotive industry is a key industry in South Africa and has been a recipient of government incentives in various forms for many decades. The intention of the latest version of the Motor Industry Development Programme (MIDP) was to support the industry to become globally competitive in the long-term. Ten years after commencement of the MIDP, the effectiveness of the programme in supporting industry competitiveness is being reviewed. The MIDP policy framework was based on intuition and consensus among stakeholders. Model assumptions on the program remain embedded in the mental models of its historical promoters, making it hard to discern internal inconsistencies. The problem with intuitive models is that they cannot be scientifically assessed to allow objective analysis and improvement. Formalising of intuitive mental models enhances their quality and increases the reliability of their simulations, an aspect critically important for policy intervention improvement (Richmond, 2004, p.6). This chapter presents a formalisation of the Productive Asset Allowance (PAA) and, by extension, the Import-Export Complementation (IEC) incentives of the MIDP, using a system dynamics approach. The first section recasts the static uni-directional MIDP incentive model into qualitative causal loop diagrams, capturing the main feedback effects within the industry relevant to the offer of government incentives. The second section presents quantification of the incentive model by way of capturing equations underlying its structure. Parameter estimation and issues pertaining to model validity are addressed in the last section.

## 6.2 Causal loop diagrams of the MIDP incentives

### 6.2.1 The PAA

From a system dynamics and conceptual perspective, the level of investment incentives receivable under the PAA increases with aggregate industry investment. With all other factors constant, an increase in investment will increase investment incentives obtainable. The increased value of investment incentives received will motivate further investment, which will in turn increase the value of investment incentives receivable. A reinforcing investment process is created. This is captured by an investment reinforcing causal loop named 'investment multiplier' in Figure 13. The reinforcing investment-investment incentive loop in Figure 13 is valid to the extent there are no intermediary factors that constrain increase in domestic investment. Since this is a less likely scenario, investment was modelled to be constrained by domestic market potential as explained below.

Rebates generated through investment directly increase the value of import rebates awarded to the industry and consequently increase the value of rebatable imports. The value of rebatable imports crowds out part of the domestic production, hence negatively affecting domestic production potential – the basis on which domestic production decisions are based, holding other factors constant. If domestic production potential is low, investment rates will be adjusted accordingly, leading to a subsequent downward revision of planned investment. With reduced investment, fewer rebates are generated, counteracting the already noted negative impact of rebatable imports on the production potential. The process constitutes a counter-balancing loop denoted as C in Figure 13. It should also be noted that the domestic production potential is also a function of other factors; the most important and most relevant ones to the research question being the size of the domestic market and exports. Both factors have a positive effect on the domestic production potential.

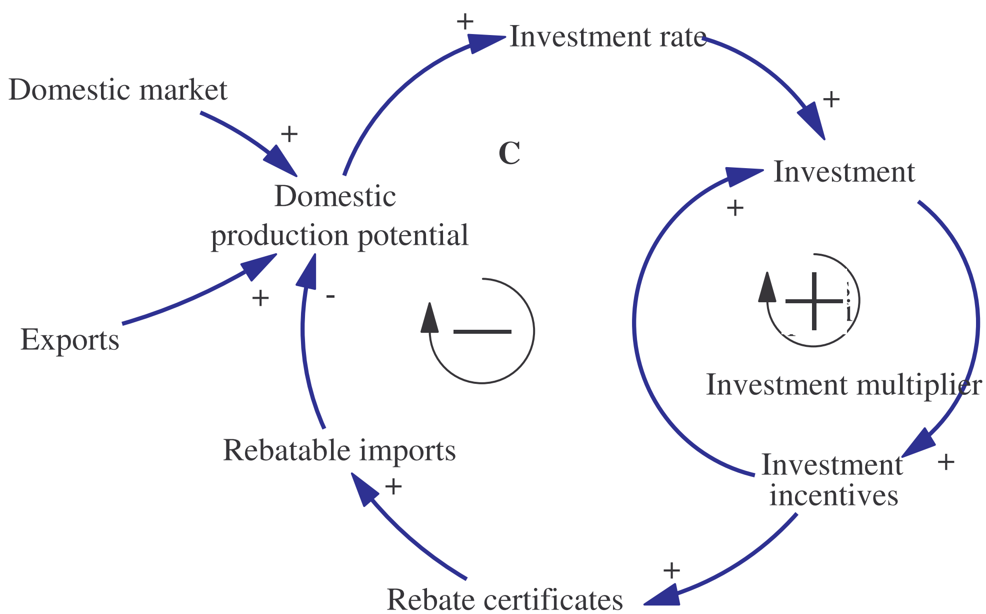


**Figure 13: MIDP investment-investment incentive causal loop diagram**

### 6.2.2 Import-export complementation arrangement

Analysing the effect of the PAA on industry performance dynamics cannot be done in isolation of the Import-Export Complementation (IEC) incentive dispensation. The PAA augments the stock of industry rebatable imports generated under the IEC dispensation; therefore, it is a major source of industry dynamics and feedback effects. Under the arrangement, companies exporting automotive products receive IRCCs based on the local content value exported. The arrangement is based on the assumption that increase in exports will drive domestic industry growth. For domestic companies to be able to export, they must produce world-class automotive products at globally competitive prices. Indirectly the incentive motivates the domestic industry to attain economies of scale and efficient production means. Achievement of efficient production levels is directly related to investment in productive assets and R&D efforts within the industry; as such the PAA and IEC effects are interrelated in supporting the industry competitive objective.

In terms of systemic relationships, increase in exports will increase the value of IRCCs receivable by the industry. Since companies can only benefit from the IRCCs received through offsetting duties payable on imports, the value of available IRCCs increases industry propensity to import. Duty free import, whose value depends on domestic wholesale value of vehicles, further augments the propensity to import since IRCCs are used to pay import duty net of the duty-free allowance.

By default, therefore, the import-export complementation arrangement has a delayed feedback effect on domestic production through the import propensity effect. If the domestic market growth happens to be less than the industry import growth rate, the effective market available for locally manufactured automotive products will decrease. Unless the increase in export is significant enough to offset reduction in the domestic market share of locally produced automotive products, domestic production will drop in the long run. Decrease in domestic production will decrease the value of IRCCs receivable via the export variable; mitigating against the continued decrease in local production. The import-export complementation loop is, therefore, counterbalancing.

In acknowledgment of the process towards long-term competitiveness, the delayed but positive effect of domestic R&D is introduced in the import-export complementation Causal Loop Diagram (CLD).  Figure 14 below presents the functioning of import-export complementation in a high-level casual loop diagram.

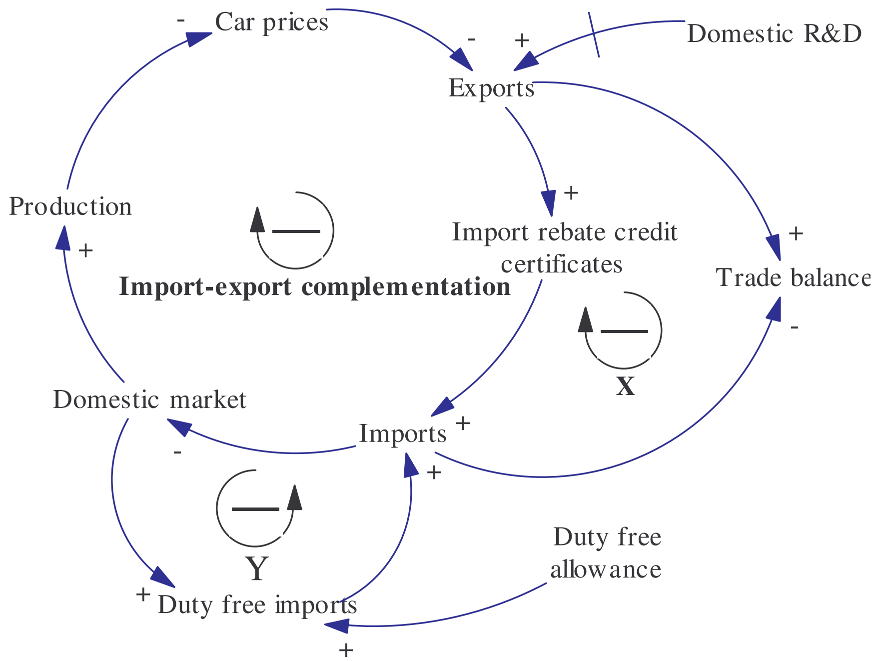


**Figure 14: Import-export complementation causal loop diagram**

Of much recent interest to stakeholders and the motivation behind this study, is the impact of the import-export complementation arrangement on industry trade balance. Exports improve industry trade balance; yet, on the other hand, exports increase propensity to import via export-based IRCCs. The resultant effect is another counter-balancing, but incomplete trade balance loop X shown in Figure 14.

Another counterbalancing loop pertaining to the IEC dispensation relates to the generation process of duty free imports. By definition, the value of duty free imports depends on the prescribed duty free allowance (percentage) and sale value of locally manufactured vehicles in the domestic market. As such, both the domestic market and duty free allowance have a positive influence on duty free imports. Duty free imports add to the stock of industry imports. As explained previously, imports in general, have a negative affect on the effective domestic market. This relationship between the domestic market, duty free allowance, duty free imports and industry imports is captured in the counterbalancing loop Y in Figure 14.

Although Figures 13 and 14 are separately presented, they are part of a single industry system. Due to the complexity of cause and effect involved between different variables, the human mind may not fully comprehend and anticipate outcomes of the combined interrelationships presented. Indications of likely outcomes are only possible through quantification of the model and simulation of scenarios. The qualitative articulation of the MIDP model, from a system dynamics perspective and using CLD above, provides a necessary foundation for quantification and simulation of the effects of South Africa's automotive incentives to industry performance. The quantitative modelling of the PAA and IEC is presented in the following section.

## 6.3 The MIDP Incentive Model

### 6.3.1 PAA model structure

Under the PAA dispensation, only investment in new and unused productive assets qualifies for benefit. Modified or refurbished assets may qualify for the PAA at the discretion of the International Trade Administration Commission (ITAC) workgroup, but in any case, such assets have to be declared and motivated at a project application stage. The value of assets qualifying for the PAA is therefore a proportion of total industry investment that can be captured by the equation:

$$P_{AA}I_t = \alpha I_t \tag{1}$$

where $P_{AA}I_t$ is the PAA qualifying investment in the year t, α is the PAA qualifying investment fraction and $I_t$ is total annual industry investment.

Benefit from the qualifying investment takes the form of import rebates and is set at 20% of the qualifying investment. The value of rebates that can be generated from a particular value of qualifying investment can be presented as:

$$P_{AA}RG = 0.2 * P_{AA}I_t \tag{2}$$

where $P_{AA}RG$ is the PAA rebates generated per annum and the 0.2 is the existing PAA benefit fraction.

Since the benefit from the PAA is spread over a five-year period, the value of annual rebate certificates that can be generated is according to the equation:

$$RCR = P_{AA}RG/5 \tag{3}$$

where $RCR$ represents the value of rebate certificate release per year and the 5 represents the five-year period over which the PAA benefit is spread.

The value of imports that can be brought into the country using PAA rebates depends on prevailing import duty and the value of rebates issued in a particular year according to the equation:

$$P_{AA}RI = RCR/IMPORTDUTY \tag{4}$$

where $P_{AA}RI_t$ is the value of imports that can be brought in the country, using the PAA rebates and *IMPORTDUTY* is the prevailing import duty in the year under consideration.

Figure 15 presents the PAA stock-flow diagram capturing relationships defined in equation (1) up (4). Stella software ‘array’ modelling capabilities were used to capture delays in the issue certificates generated in each year of investment.

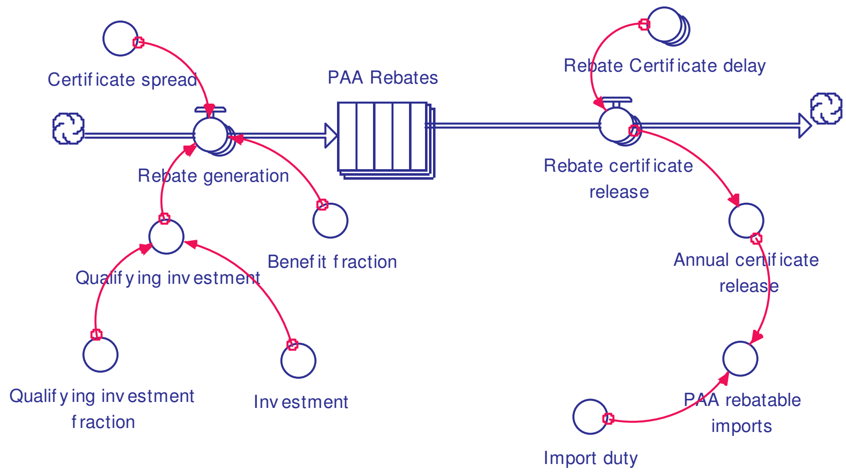


**Figure 15: PAA stock-flow diagram**

Next, the feedback effect of PAA rebates was incorporated. The first step was to make industry investment endogenous. This was done by introducing the investment rate variable. Industry Investment per year was set to depend on annual investment rate i.e.

$$I_t = I_{t-1}\left(1 + I_{rate}\right) \tag{5}$$

where $I_{rate}$ is the annual investment growth rate.

The investment-investment rate feedback effect was captured in a simple stock and flow diagram in Figure 16 depicting a potential exponential increase in industry investment over time. It is acknowledged that the use of growth rates lead to exponential growth in stock values and this may bias model extrapolation results over long periods. The timeframe for the MIDP is up 2020, which cannot be considered an excessively long period. Historical data should strongly support this exponential growth; otherwise, the rates may need to be adjusted as more recent data become available.

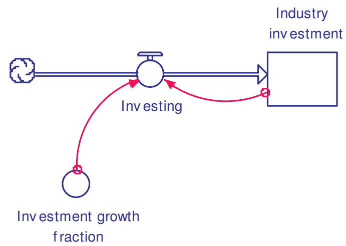


**Figure 16: Industry investment feedback loop**

One of the most import aspects of system dynamics modelling and a source of insights into system performance is the identification of feedback effects that often constitute closed loops. In order to close the PAA incentive model and against the background of the fact that investment depended on planned production, two local production potential explanatory factors other than rebatable imports: domestic market and exports were introduced. It is widely acknowledged that local market size is a major factor in investment location decision particularly in the automotive industry. Jenkins & Thomas (2002, p. 44) mentions that the size of the local market is believed to the most important motivation for European subsidiary companies in Southern Africa. European subsidiary companies happen to be strongly represented in South Africa's automotive industry. Exports augment the domestic market size while imports, whether rebated or otherwise, reduce the effective domestic market.

PAA rebatable imports add to the stock of industry imports into the country on which the industry did not pay duties. Given that the only way industry could benefit from the PAA incentive was through importing and offsetting duties payable using earned rebate certificates, firms would tend to import until they have exhausted import rebates received.

To account for the effects of domestic market size, exports and PAA rebatable imports on investment, the normal-investment-growth fraction variable was introduced. At this stage of model construction, both domestic industry and exports were taken to be static. To the extent that the above three variables affect investment, actual investment growth fraction would differ from the normal growth fraction. The difference would be the effect emanating from production potential factor (the basis of domestic production plans), which was postulated to be proportional to: *(domestic market + exports –PAA rebatable imports)/ (domestic market + exports)*. The logic of the equation was that as long as there are no rebatable imports, investment would grow at a normal rate dictated by the size of the domestic market and export potential.

The effect of PAA rebatable imports on production potential factor, which in turn affected the actual investment growth fraction, constituted a closed loop of the PAA incentive model presented in Figure 17. The feedback loop is implicitly non-linear based on the value of rebatable imports and exports. Increase in the value of rebatable imports relative to the export value mitigates against high increases in investment through its effect on actual investment growth fraction and vice-versa.

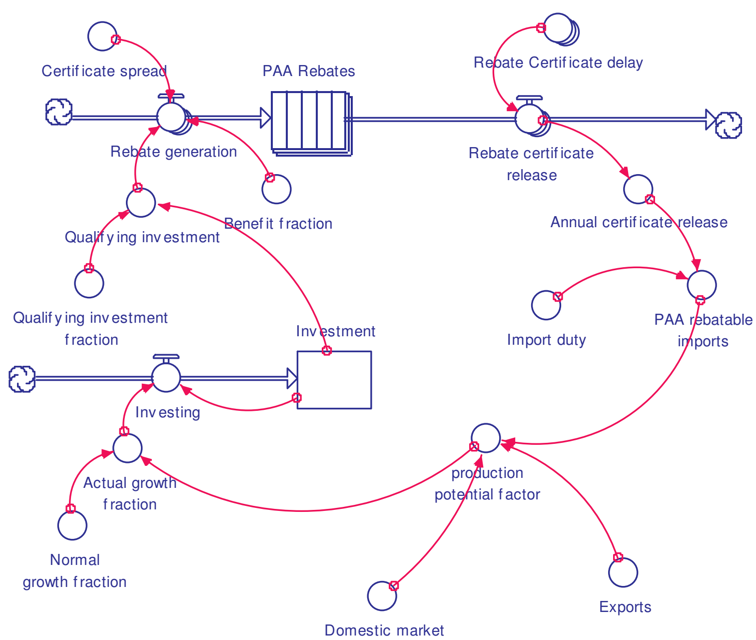


**Figure 17: Closed loop stock-flow diagram for the PAA**

By specifying initial model values and providing input values, the PAA model presented in Figure 17 enables simulation of the value of rebatable imports under different scenarios pertaining to the PAA benefit policy rule.

As highlighted previously, the effect of rebatable imports on production planned was underestimated in the PAA model above, as it did not take into account additional rebatable imports generated through the import-export complementation dispensation. In the following section, the model was therefore extended to include the import-export complementation dispensation, which contributed also to the value of rebatable imports in the industry.

### 6.3.2 Import-export complementation incentive model

Under the import-export complementation dispensation, firms earned Import Rebate Credit Certificates (IRCCs), based on a proportion of exported local content. Exports were specified as being determined by export growth rate, which rate was assumed exogenously determined - OEM exports are largely dependent on parent decisions but may be influenced by incentive offer. As such, the equation for industry exports per year could be presented as:

$$E_t = E_{t-1}(1+\beta) \qquad (6)$$

where $E_t$ is total industry exports per annum in the year t, and $\beta$ is the export growth rate fraction.

It followed that the exported value of local content is captured by the equation:

$$ELC = ELCF * E_t \qquad (7)$$

where *ELC* is the exported value of local content and *ELCF* is the exported local content fraction.

In terms of calculating the IRCC value to be awarded to an exporting entity, the exported value of local content was discounted at a rate determined by Government. The IRCC value generated, therefore, was a function of exported local content and the exported local content beneficiation fraction as determined for a particular year. Equation (8) below captures this relationship:

$$IRCCVALUE = ELC * LCBF \qquad (8)$$

where *IRCCVALUE* is the value of IRCC generated per year, and *LCBF* the export local content beneficiation fraction.

By definition, the value of rebatable imports was equivalent to the value of IRCCs issued and is independent of the import duty rate. Figure 18 presents the import-export complementation model for generating IRCCs and subsequently rebatable imports.

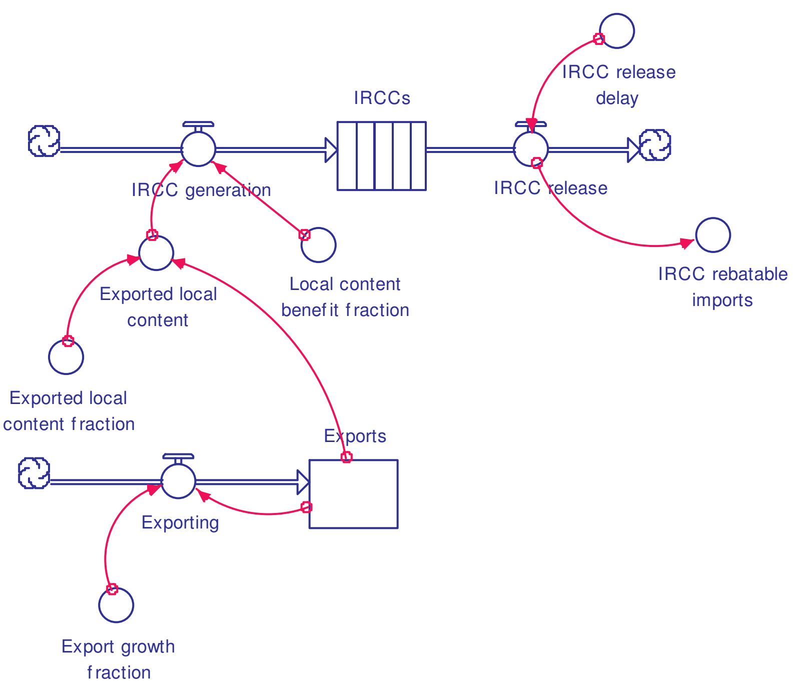


**Figure 18: Import-export complementation stock-flow diagram**

IRCCs generated under the IEC dispensation added to the overall stock of industry rebatable imports. To estimate the overall effect of rebatable imports on production plans, the PAA model and the IEC model were combined. A new variable, namely industry rebatable imports, which was a summation of PAA rebatable imports and IRCC rebatable imports was introduced. The direct link between PAA rebatable imports and production plans was removed and instead a link between PAA rebatable imports and industry rebatable imports on one hand, and IRCCs rebatable imports and industry rebatable imports on the other, was created. Thereafter, industry rebatable imports were linked to production potential factor. An important aspect to take note of under the combined PAA-IEC model was the fact that exports and the domestic market were allowed to vary over time through introduction of respective growth rates. The combined PAA-IEC model structure is presented in Figure 19.

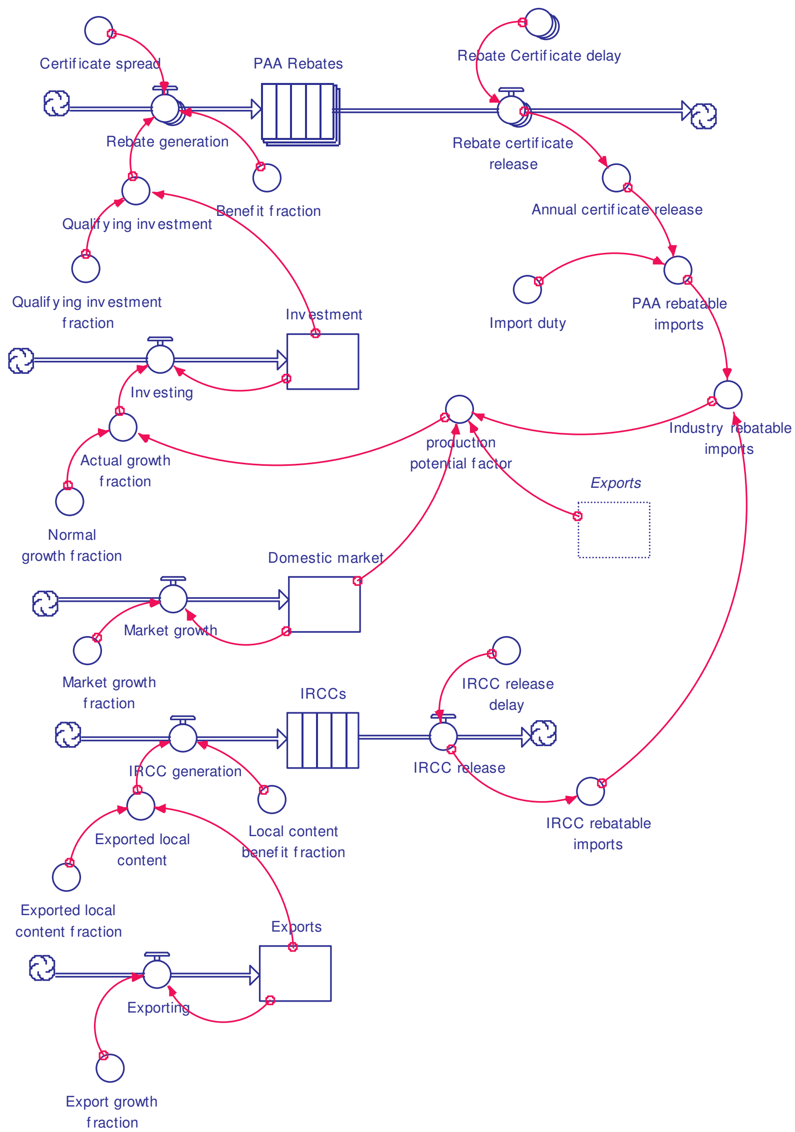


**Figure 19: Combined PAA-IEC model structure**

As in the case of causal loop diagrams, the PAA-IEC model was extended to include the industry trade balance variable. Introducing the trade balance variable allows sensitivity analysis of the industry trade balance account in response to a policy decision on the PAA and IEC incentive dispensations of the MIDP.

Industry imports were specified as an endogenous variable that depended on the import decision. The domestic market and the value of rebatable imports at industry level influenced the import decision. Before a firm within the industry could import, it had to have some insight into how much imports the domestic market could absorb. After establishing the import absorption capacity of the domestic market, the firm will have to consider the almost mandatory import it has to undertake in order to make use of import rebates earned. Hence, the postulation that the domestic market and rebatable imports were determining factors of the import decision. If there was no commensurate increase in the domestic market, there was a high likelihood that as rebatable imports increased, industry imports would also increase.

In the quantification of the model and behind the import decision, the impact of domestic market and rebatable imports on imports growth fraction was specified as being dependent on the ratio of industry rebatable imports and the domestic market. This impact declined as the value of rebatable imports tended toward the domestic market size. Figure 20 presents the extended PAA-IEC-Trade Balance model structure. The PAA-IEC-Trade model in Figure 20 could be quantified and used to simulate effects of the PAA and IEC policy variable on industry trade balance.

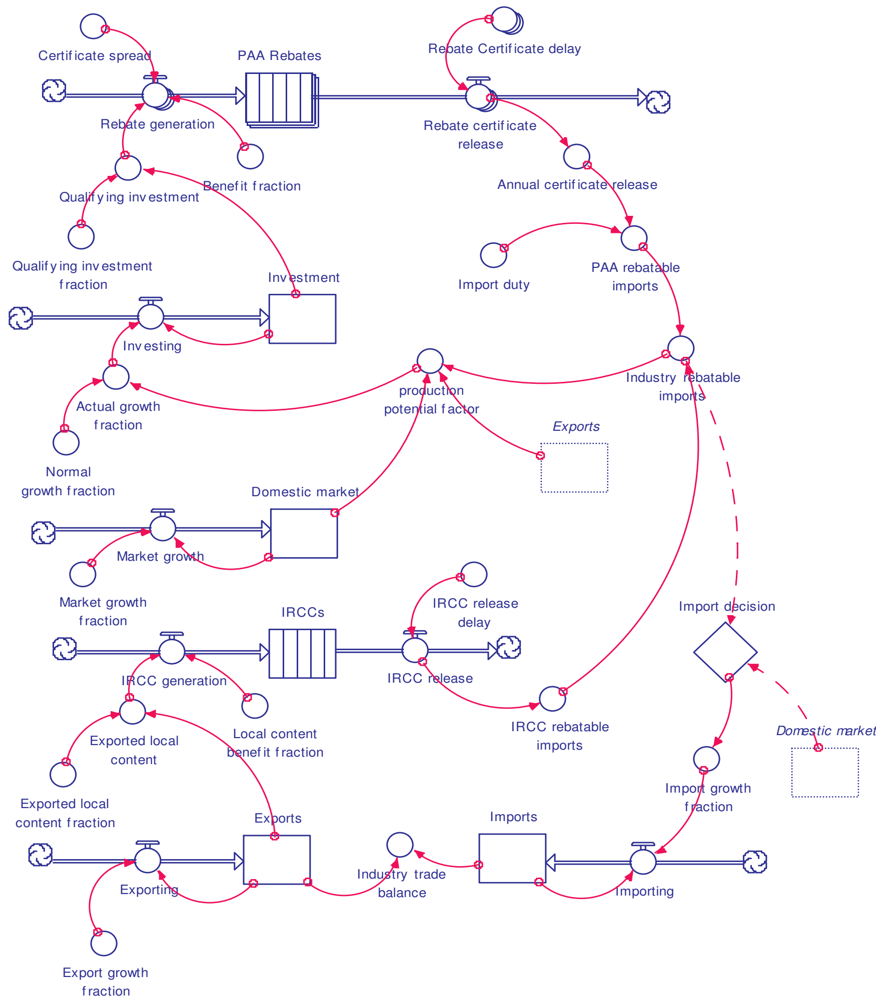


**Figure 20: PAA-IEC-Trade Balance model structure**

## 6.4 Model validation and testing

After formalisation of the PAA-IEC-International Trade model, the next step was to validate the model. Despite the wide use of the word 'validation' in modelling literature, models cannot be validated – if validation is taken to mean establishing truthfulness of the model. This is so because all models are a simple representation of reality developed with a mindset biased towards what the model intends to do and for whom it is intended to serve. What can be validated, however, are the analytical statements and propositions derived from the axioms of closed logical systems (Sterman, 2000, p.846). The issue is not about the validity of the model but its usefulness. When system dynamists talk about model validation, they are often referring to ways to make the model useful and acceptable to the intended clientele, a process that is more subjective than scientific. Referring to model validation Forrester (1961, p.123) wrote:

> *Objective model-validation procedure rests eventually at some lower level of judgement or faith that either the procedure or its goals are acceptable without objective proof.*

According to Richardson and Pugh (1981, p.310), model validation is not about establishment of the truthfulness of a model under consideration but rather a process that lead to people placing confidence in a particular model. They add that despite the well-documented steps in system dynamics modelling, there is little agreement about what good model validation is or ought to be. As a guide to ascertaining model validity Richardson and Pugh (1981, p.312) suggest that the modeller should instead answer two fundamental questions:

1. Is the model suitable for its purposes and the problem it addresses?
2. Is the model consistent with the slice of reality it tries to capture?

In practical terms, therefore, model validation takes the form of tests carried out on the model to increase its acceptance to the intended audience. The tests should check both structural and behavioural dimensions of the model (Richardson and Pugh 1981, p.314; Sterman, 2000, p.859). Sterman (2000, p.859-891) lists and explains 11 tests for assessing dynamics models that were adopted and extended from Forrester and Senge (1980):

- Boundary adequacy
- Structural assessment
- Dimensional consistency
- Parameter assessment
- Extreme conditions
- Integration error
- Behaviour anomaly
- Family member
- Surprise behaviour
- Sensitivity analysis
- System improvement

Sterman cautions that no one of these tests is adequate but a wide range of tests helps in understanding robustness and limitations of a model. Likewise, Richardson and Pugh (1981, p.314), created a summary of model tests in the form of a matrix mapping testing of suitability, consistency, utility and effectiveness to structural and behavioural aspects of the model (Table 21).

| | Focusing on STRUCTURE | Focusing on BEHAVIOUR |
|---|---|---|
| Testing SUITABILITY for purpose<br>(tests focusing inward on the model) | Dimensional consistency<br><br>Extreme conditions in equation<br><br>Boundary adequacy<br>important variables<br>policy levers | Parameter (in)sensitivity<br>behaviour characteristics<br>policy conclusions<br><br>Structural (in)sensitivity<br>behaviour characteristics<br>policy conclusions |
| Testing CONSISTENCY with reality<br>(tests comparing the model with information about real system) | Face validity<br>rates and levels<br>information feedback<br>delays<br><br>Parameter values<br>concept fit<br>numerical fit | Replication of the reference modes (boundary adequacy for behaviour)<br>problem behaviour<br>past policies<br>anticipated behaviour<br><br>Surprise behaviour<br><br>Extreme condition simulations<br><br>Statistical tests<br>time series analyses<br>correlation & regression |
| Contributing to the UTILITY and EFFECTIVENESS of a suitable, consistent model | Appropriateness of model characteristics for audience<br>size<br>simplicity/complexity<br>aggregation/detail | Counter-intuitive behaviour<br>exhibited by model<br>made intuitive by model based analyses<br><br>Generation of insights |

**Table 21: Summary table of tests for building confidence in system dynamics models** (Richardson and Pugh, 1981, p.314).

> *Any of these tests by itself is certainly inadequate as an indicator of model validity. Taken together, they form a formidable filter, capable of trapping and weeding out*

*models and allowing passage only to those most likely to reflect something close to the truth***.** Richardson and Pugh, 1981, p.314

There is no rule of thumb as to the number of tests that should be carried out in order to establish validity of a particular model. The onus is on the modeller to decide on the set of tests that would adequately create reasonable confidence in a model developed for a particular purpose. Given the applied nature of this research project, explicit model structural tests were not carried out but rather an exploration of issues pertaining to model structure validity and thereafter model behaviour tests were conducted. As pointed out previously, the structure of the incentives model was not hypothetical. The PAA and the IEC were already in place and operational. Qualitative information by way of incentive offer guidelines provided the qualitative structure of the model. Hence, it was felt that structural tests would not be value adding in this regard.

### 6.4.1 Model structure tests

The ultimate objective of structural validity and hence of model structure testing is to ascertain that a model under consideration is a fair meaningful description of real relationships underlying the dynamic behaviour under study. Structural validity has to be established before one can proceed to behavioural validity, otherwise the latter will be pointless. Establishing model structural validity was not contentious because the qualitative and intuitive MIDP incentive framework was already in place and well documented. The researcher's role in this respect was to formalise the intuitive policy framework into a SD model by capturing the major source of dynamics relevant to the research problem and question. In formalisation of an policy frameworks already in existence, structural tests are continuously carried out in the sequential model building process. By the time the researcher comes up with a complete model on which behavioural tests can be done, the structural tests and validity would have been accomplished to a large extent. Structural validity is carried out through careful documentation of qualitative information on the policy framework and verifying the structure with stakeholders and experts at each stage of the model building process. In this regard, the PAA Guidelines and ITAC-Stakeholders documents pertaining to MIDP incentives provided well-documented reference notes on the structure of the PAA and IEC. On the IEC for example, the NAACAM Directory (2007, p.8) explains:

> *The import-export complementation scheme allows for reductions of import duties on cars and light commercial vehicles according to the value of local content exported. For every Rand of CBU exported, a percentage determined by Value of Export Performance (VEP) of CBUs may be imported free of duty. For every Rand of components exported, a percentage determined by the VEP of components may be imported free of duty. Value of Export Performance equals to the local value added of FOB price multiplied by a discount factor. The scheme is controlled by the issue of Import Rebate Credit Certificates (IRCCs) to registered importers once the foreign funds have been repatriated and all documentation completed.*

The PAA Guidelines (ITAC, 2005, p.5&9) on the other hand describes the working of the PAA incentive as follows:

> *The PAA provides for a rebate of the duty on imported completely built- up light motor vehicles to the extent of 20 per cent of the value of the investment in productive assets approved by the International Trade Administration Commission (ITAC). The rebate of 20 per cent will be spread equally over a period of 5 years at 4 per cent per annum, is non-tradable between companies and may only be used by the approved light motor vehicle manufacturer to import specified light motor vehicles. Only new or unused plant, machinery and tooling used for the sole purpose of manufacturing the rationalised range of light motor vehicles or automotive components for such light motor vehicles will qualify for purposes of the PAA.*

Due to the well-defined qualitative information of the PAA and IEC incentive functioning, expert opinion on the model structure was carried more as a re-affirmation of the model structure rather than bringing new insights to the model structure.

The choice of important variables to be included in the model was dictated by the reference mode – industry trade balance and industry variables upon which the incentives are based and on which the incentives have a direct effect. In this regard, the key variables on the development of the incentive model were imports, exports, investment, PAA rebates, IRCCs stock and the domestic market.

Given the steps taken in developing the formal model above, the testing of model consistency with reality and dimensional consistency was largely redundant. Since the modelling task was a formalisation of an already existing incentive framework that has been operation for a while, there was no fundamental difference between the incentive dispensation in reality and the formal model developed. Stocks were identifiable from the qualitative data while rates of changes could be computed from historical data and verified via expert opinion. Likewise, the sequential model building process accomplished conceptual fit. Stocks were captured as values in billion rand while rates and ratios were unitless.

In summary, structural validity testing was carried out from the model conceptualisation until the model simulation stage. The model was simulated only after ascertaining structural validity for each of small model sections, which finally constituted the aggregated model. As previously noted, three independent experts on the MIDP incentives portfolio assisted to validate the model structure as explained in the preceding section.

### 6.4.2 Behaviour tests

Establishing behaviour validity and hence model behaviour testing deals with ascertaining that the dynamic pattern generated by the model is close enough to the real dynamic pattern of interest. The behaviour dimension of the model has much to do with parameters used in simulating a model. Most parameters in system dynamics studies are estimated based on descriptive information obtained from participants in the system being modelled (Graham, 1980, p.144). For this research project, three aspects eased the process of parameter estimation:

1. Existence of a comprehensive set of guidelines relating to policy rules on industry incentives. Many of the parameters are specified in these guidelines. For example, the nature of investment and the fraction of that investment that translates into PAA rebates is specified in the guidelines.
2. Existence of time series data from which rates of change over time could be computed. The rates of change were used as reference variables that would make sense to both the researcher and stakeholders. Using historical rates of change, it was possible to use the phrase ‘if the status quo was to hold in future’ in communicating model results.
3. Most of MIDC representatives were professionals in their own right. They motivated their point of view using quantitative data, giving some indication of relevant parameter values.

A summary of parameter and rates of change used in the model, and their base of estimation is presented in Table 22. Comparisons between the actual values of investment, domestic market and exports as per the historical data, and the respective values per the growth fractions used to simulate the model are presented in appendix 4. The duty rate schedule for Built-up light vehicles and Original equipment components for the period 1999 to 2012 is also included.

| Parameter | Value | Comment |
|---|---|---|
| Normal investment growth fraction | 15% | Based on quantitative historical data |
| Domestic market growth fraction | 9% | Based on quantitative historical data |
| Export growth fraction | 27% | Based on quantitative historical data |
| Import growth fraction | Varying | Based on domestic market and rebatable imports |
| PAA benefit fraction | 0.2 | Factual |
| PAA certificate spread | 5 (years) | Factual |
| Import duty | 0.3 | Factual but can changing over time |
| Export local content fraction | 0.9 | Based on historical data |
| Exported local content benefit fraction | 0.7 | Factual but can changing over time. Figure was adjusted to capture impact precious metal group special dispensation. |
| Impact of domestic market and rebatable imports on production plan | Varying | Based on qualitative and quantitative historical data |
| Impact of domestic market, exports and rebatable imports on import decision | Varying | Based on qualitative and quantitative historical data |

**Table 22: Model parameters for the PAA-IEC-Trade balance model**

Even after defining model validation as a set of steps to undertaken to build confidence in a particular model it has to be done in context of the model purpose. In this respect, the first model behavioural test is often the establishment of whether the model can replicate the reference mode.

#### 6.4.2.1 Model behaviour vis-à-vis the reference mode

Although it is widely acknowledged that the objective of system dynamics modelling is not point prediction of a system performance but rather to probe dynamics underlying a particular behaviour, it is important that an SD model can endogenously reproduce the reference mode of interest. Without replication of the reference mode, the model becomes irrelevant in providing insight into the problematic situation and as such cannot be useful. Richardson and Pugh (1980, p.317) claim that if a model cannot reproduce its reference behaviour mode, it is invalid. The first behavioural test undertaken was to assess whether and to what extent the model reproduced the reference mode behaviour – the exponentially increasing industry trade deficit. The base run showed that the model could endogenously replicate the reference mode behaviour (Figure 21). Replication of the reference behaviour and from an indigenous perspective indicated that the model could be valuable in highlighting leverage variables or points of action that could influence the deteriorating industry trade balance.

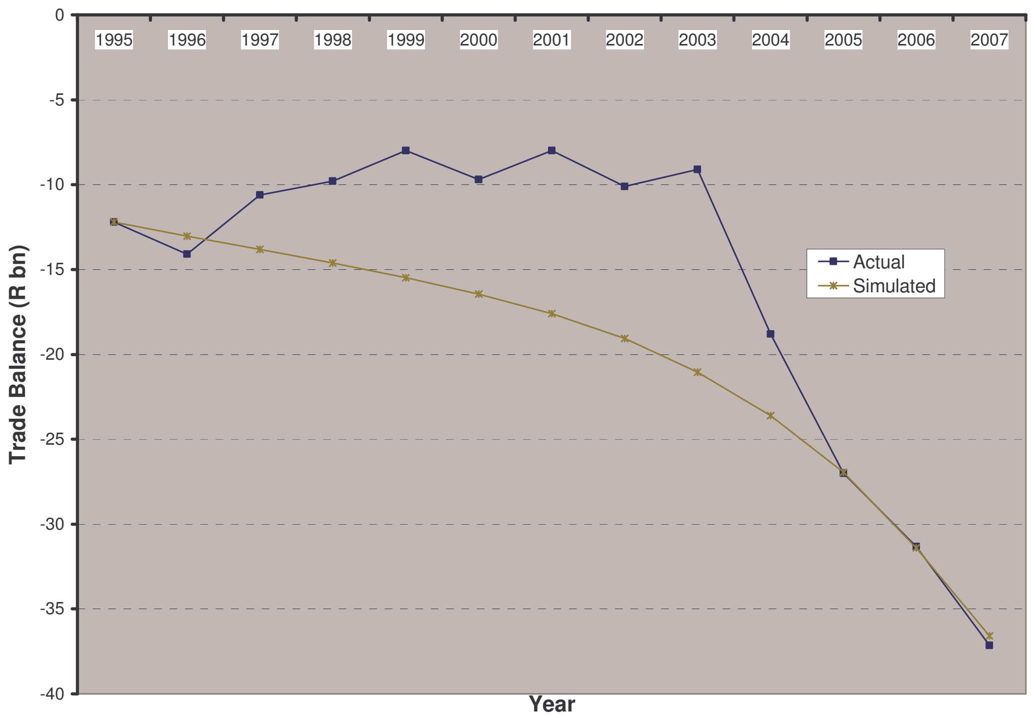


**Figure 21: Model replication of the reference mode behaviour**

The base model run showed weakness in predicting improvement in industry trade balance in the first five years of the MIDP, though it rightfully captured the deteriorating industry trade balance thereafter. The deficiency was not considered critical as model simulation over a longer period confirmed that the model could reproduce the general trend of the problematic behaviour.  Again, the ultimate aim of policy-oriented system dynamics modelling is to reveal behaviour pattern rather point forecast.  The complete set of Stella model equations for the base run reproducing the reference mode are presented in Appendix 5.

#### 6.4.2.2 Model behaviour under extreme conditions

An important test of model validity is the check on how the model behaves under extreme conditions.

> *"Models should be robust under extreme conditions. Robustness under extreme conditions means that the model should behave in a realistic fashion no matter how extreme the inputs or policies imposed on it may be",* Sterman (2000, p.869).

In terms of extreme condition tests and relative to the industry incentives, model behaviour was tested under the following situations:

1. All investment qualifying for the PAA translates into rebate certificates i.e. setting PAA benefit fraction as 1.
2. None of the PAA qualifying investment translates into rebates i.e. setting PAA benefit fraction as 0.
3. There is no discounting of exported local content in calculating IRCC value awarded to industry exporters i.e. setting export local content benefit at 1.
4. None of the exported local content qualifies for rebate under IEC dispensations i.e. setting export local content benefit fraction at 0.

Figure 22 shows the extreme condition run in terms of PAA rebatable imports and industry trade balance when all investment qualifying for the PAA translates into rebate certificates. For the period 1995 to 2001, the PAA rebatable imports equal to 0 as the first certificates were only issued in 2002. After 2002, the value of rebatable imports starts to increase gradually but is insignificant in terms of the overall reference mode behaviour. The simulated behaviour was in line with reality, regarding the low value of PAA rebatable imports relative to the overall industry trade account. At this point it was also recognised that the industry trade balance starts to improve after some time.

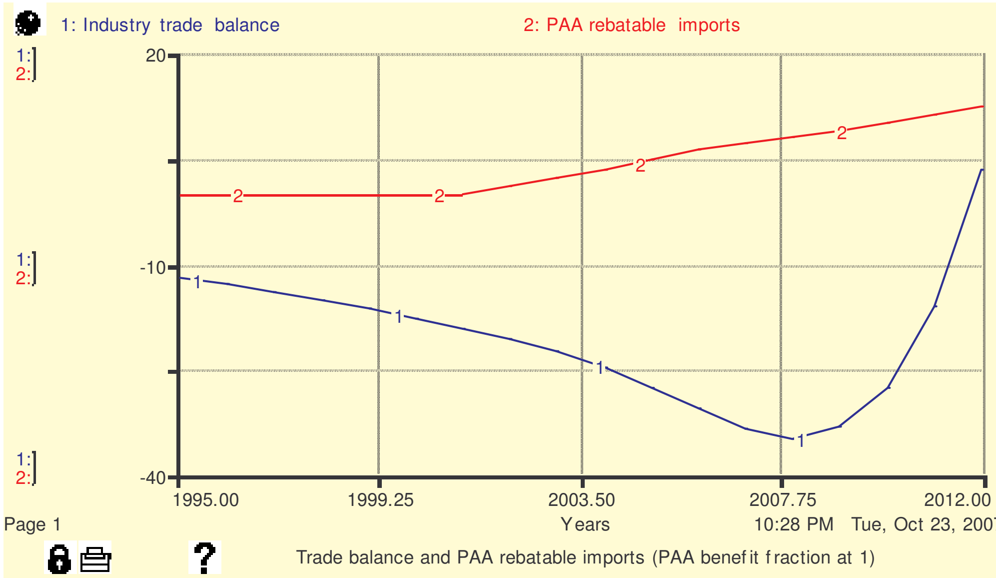


**Figure 22: Trade balance and rebatable imports - PAA benefit fraction of 1**

The opposite extreme run in which the PAA benefit fraction is set at 0, that is, none of the qualifying PAA investment translates into PAA benefit was examined. It was expected that the PAA rebatable imports would remain 0 throughout the simulation period and the reference mode would still remain unchanged given the small proportion of PAA rebatable imports relative to size of industry trade deficit. This was confirmed by the extreme condition run in Figure 23.

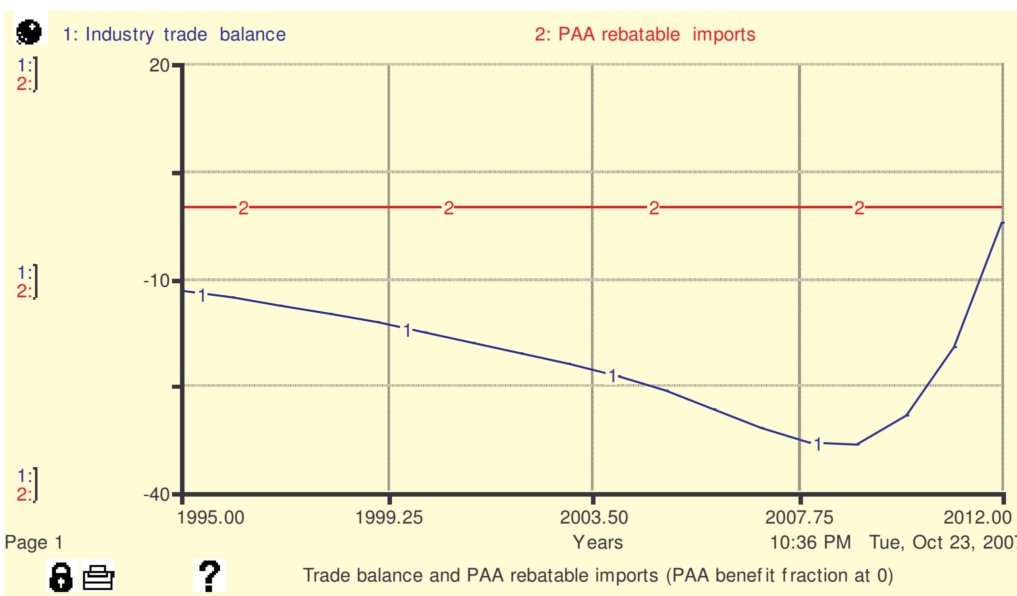


**Figure 23: Trade balance and rebatable imports - PAA benefit fraction of 0**

The two extreme tests on industry investment that translates into PAA rebates confirmed implicitly that other policy variables affecting the value of PAA qualifying investment can stand extreme case tests. Extreme tests confirm that the model is robust and can behave appropriately under all potential circumstances (Sterman, 2000, p.337).

The third extreme condition test on the model related to working of the IEC. The model was tested when local content benefit fraction of exported automotive products is set at the maximum of 100%. The extreme run showed a progressively increasing value of IRCC rebatable imports. Further still the run showed that the general trend in the industry's trade deficit remained the same but compared to the extreme run on the PAA, the deficit reached higher levels before it started to improve (Figure 24). This was in line with the study hypothesis that rebatable imports had a negative causal effect on the industry trade balance.

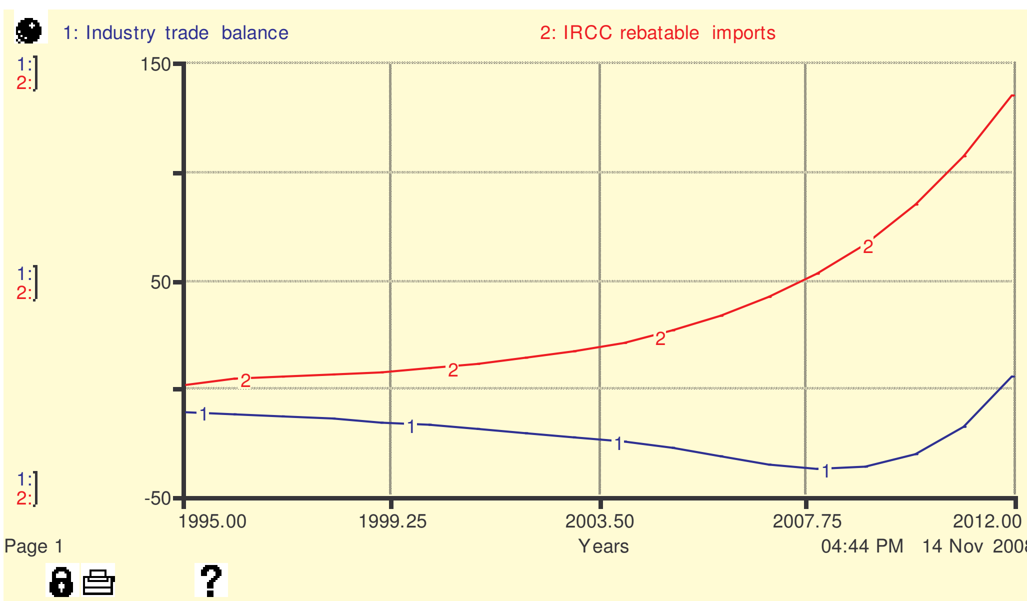


**Figure 24: Trade balance and rebatable imports - Exported local content benefit of 100%**

Fourth, the model was subjected to the extreme condition test of local content benefit fraction set at 0%, that is, none of the exported local content qualifies for the IEC benefit. The expectation was that the value of rebatable imports would remain 0 throughout and the trade deficit would not reach the high levels shown in Figure 24. This was confirmed in this extreme condition run (Figure 25). Although trade balance started as negative, with no rebatable imports the trade deficit marginally increased for a while but thereafter started to decline, becoming positive after some 10 years.

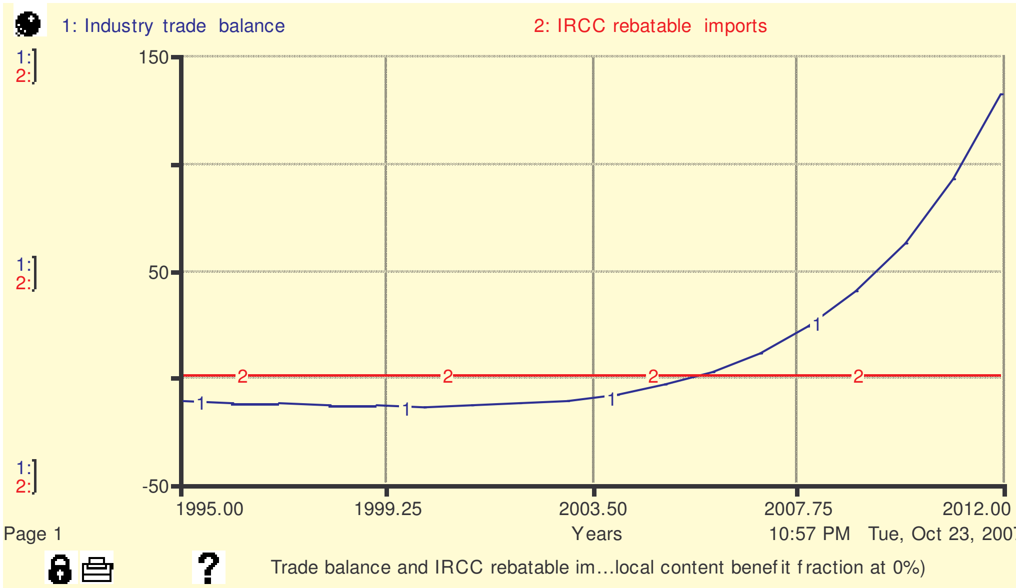


**Figure 25: Trade balance and rebatable imports - Exported local content benefit of 0%**

The simulation of trade balance trend in Figure 25 was based on the 'ceteris paribus' assumption. The reality of removing IEC benefit from South Africa's automotive industry may be different if one considers what might happen to the industry when the level of incentives is reduced. To the extent that incentives contribute towards making it viable to undertake automotive manufacturing in South Africa, without the IEC incentive, some firms may not find it profitable to locate their manufacturing activities in the country. As such, the rate of investment in the industry is likely to decline. With less investment, it is probable that the export growth rate will not be as high as hitherto presumed. For a more realistic scenario as to what might happen to the trade balance trend when industry is not getting benefit under the IEC dispensation, a decline in investment and export growth, and a probable increase in imports should be taken into account. A revised simulation of the industry trade balance with exported local content benefit set at 0, but with investment growth reduced from 15% to 10%, export growth rate lowered from 27% to 25% and import growth increased marginally to 13% is presented in Figure 26. Import growth was marginally increased to account for the likelihood that without IEC benefit to industry, import penetration would increase due to lower production volumes being planned domestically. But this import growth would, on the other hand be counteracted by less IRCCs being generated.

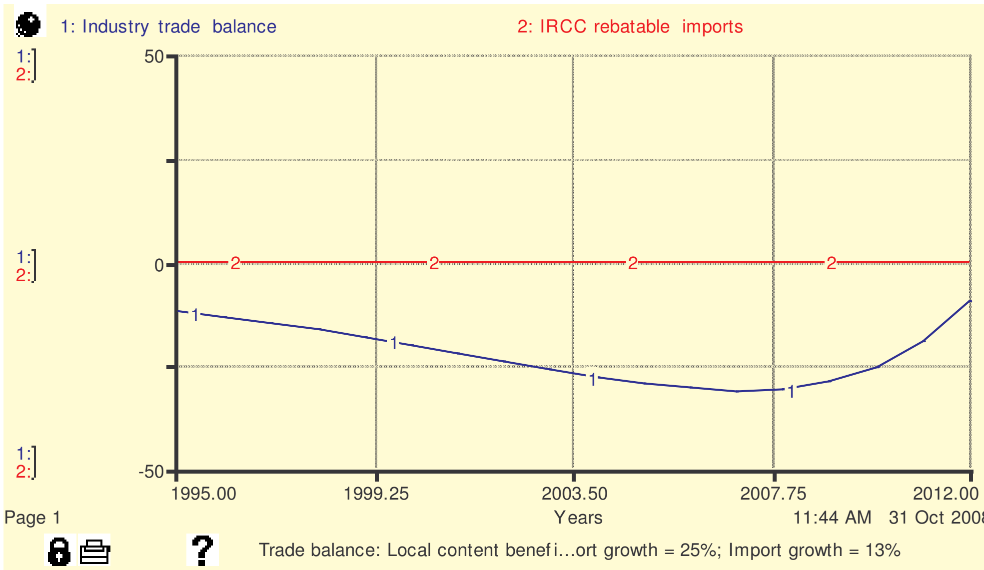


**Figure 26: Trade balance and rebatable imports - Exported local content benefit of 0% with lower investment and export growth rate and increased import growth**

The new simulation shows that even without IEC benefit, there would still be a significant deterioration in the industry trade balance but not as high as when the IEC is in place. Of course the trade balance trend in Figure 26 is dependent on the choice of the adjusted growth rates, which is a subjective process.

As was noted in the case of PAA, the two extreme tests on exports value that translates into IRCCs rebates confirm that other policy variables affecting such a value can also stand extreme case tests. This is so because such variables simply affect the stock of IRRC generated at any particular time just like the exported local benefit fraction given a particular exports value.

In general, the model behaviour did not show unrealistic results under the extreme tests. Given the nature of the research project, the extreme test also served the purpose of establishing mathematical consistency of the model. If the mathematical equations underlying the structure of the incentives model were to be wrong, likelihood would be high that model behaviour under, at least one extreme condition, would yield illogical results.

#### 6.4.2.3 Surprise behaviour

With the level of imports consistently increasing under the MIDP, driven in part by rebates availed to the industry under the PAA and IEC incentives, one was tempted to conclude that the automotive industry trade deficit would worsen indefinitely. Surprisingly the model showed that the trade deficit would be reversed after some time, if the hitherto realised export and domestic market growth rates were maintained (Figure 27).

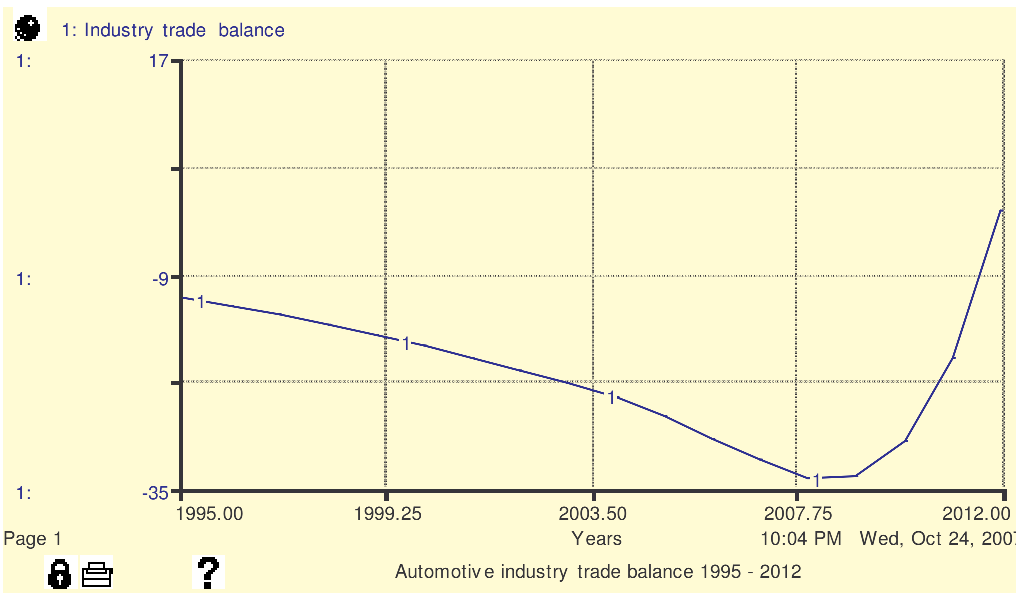


**Figure 27: Simulated industry trade balance 1995-2012**

The challenge was to make sense and explain why the industry trade deficit will be reversed. The surprise behaviour could potentially mean that the model was completely wrong. This called forth reflection on the working of the MIDP incentives.

First, the increase in both investment and exports that has characterised the South African automotive industry under the MIDP dispensation has led to the increase in rebatable imports. A decision to invest in the country depends on planned production, which in turn depends on the demand of automotive products in the country. The effective industry demand depends on the effective market demand, which is the size of the domestic market plus exports, minus imports. Although there is a portion of imports that is independent of MIDP incentives, rebatable imports are the main drivers of industry imports. As such, increase in rebatable imports has a negative impact on effective market on which production plans are based and hence crowds out investment. By implication, the continuous increase in rebatable imports will ultimately lower the rate of domestic investment and consequently reduce the positive effect of PAA rebates on industry imports in the long term.

Second, the increase in rebatable imports has a direct but switching effect on import growth rate. Initially, increase in the value of rebatable imports will have a significant effect on industry import growth. With the domestic market growth rate being lower than import growth rate, the value of rebatable imports tends to the domestic market size. As this happens, there will be less motivation by industry to import as industry will tend to balance how much to produce for the domestic market and how much to import. Industry has to maintain domestic production in order to qualify for industry incentives. At the extreme, any import rebate earned over and above the size of the domestic market has no value to the recipient since it cannot be used to import; the domestic market will be saturated already. The need to maintain domestic production while taking advantage of rebatable imports will in the long-term, reduce the impact of rebatable imports on import growth rate.

The dual effect of increasing rebatable imports on industry investment and import growth in the long term explains why industry trade deficit cannot continue to deteriorate indefinitely.

#### 6.4.2.4 Integration error test

The integration error test relates to the choice of integration method. One has to select a numerical integration method and time step that yield an approximation of underlying continuous dynamics as accurately as possible (Sterman, 2000, p.873). For a particular model to be believable, it should not be sensitive to the choice of time step or the integration method of choice. In this respect, the model was run with DT set at 1 and 0.5 using Euler's method of integration. It was found that a model outcome, in respect of the reference mode and general behavioural trend, was not fundamentally different if the time step or the method of integration was changed (Figures 28 & 29).

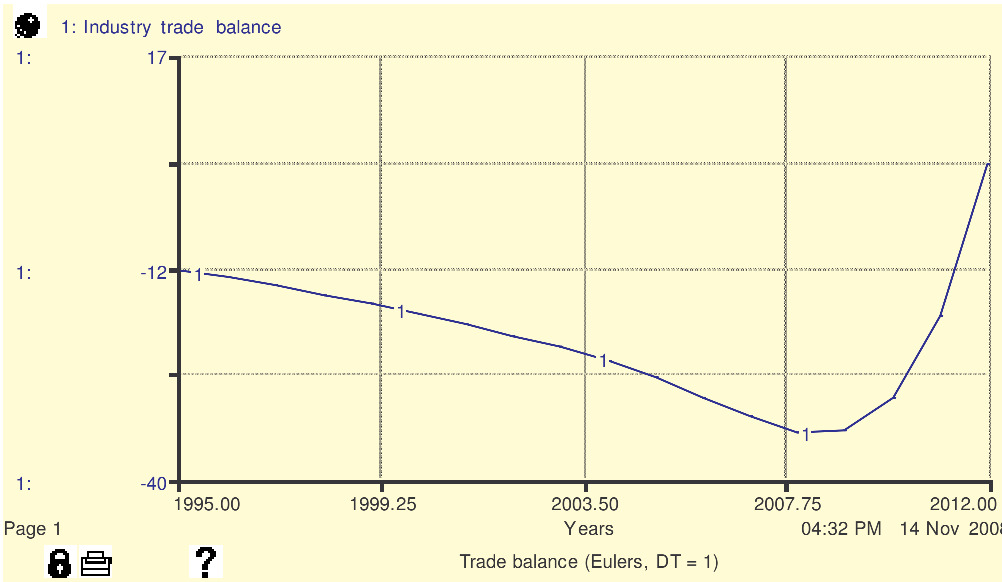


**Figure 28: Trade balance - Euler's integration method with DT = 1**

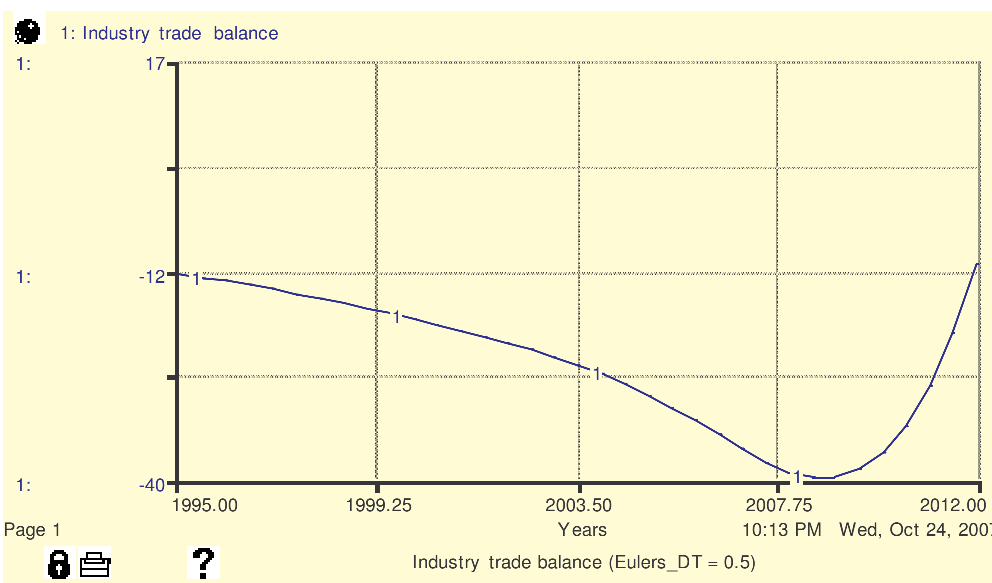


**Figure 29: Trade balance - Euler's integration method with DT = 0.5**

The model was not tested with the alternative Runge-Kutta integration methods because this model included conveyors and such higher order integration methods are not well suited to discontinuous elements (Sterman, 2000, p.910). Again, from a practical point of view, the Euler integration method simulation outputs were within acceptable range compared to industry performance time series data.

### 6.5 Model sensitivity to exogenous variables

In order to have some understanding of the extent to which variables assumed exogenous in the model could affect reference mode behaviour, sensitivity analysis of the industry trade balance to investment growth, export and domestic market rates was carried out.

Investment influences trade balance via its effect on PAA rebatable imports, which in turn affect industry imports. The reference mode behaviour was least sensitive to normal investment growth fraction. From 5% through to 15% compound annual growth rate in investment, industry trade balance trend was not significantly different from the reference mode. Significant change in the trade balance trend was realised only when the growth rate was jerked up to 50%, a very unlikely situation (Figure 30). The sensitivity analysis re-affirmed the limited influence of investment-based PAA rebates on overall industry trade balance.

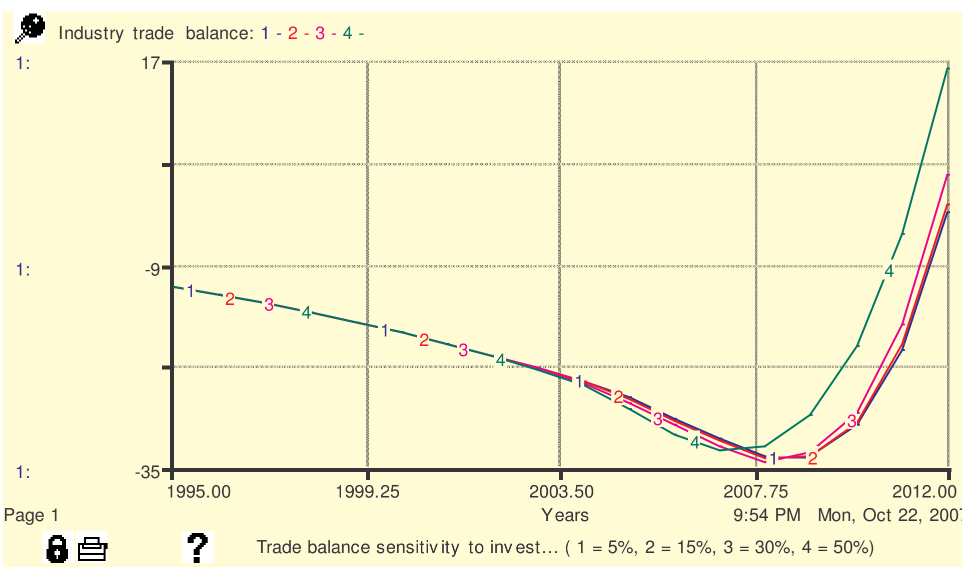


**Figure 30: Trade balance sensitivity to investment growth fraction**

In terms of industry balance sensitivity to domestic market growth, the trade balance exhibited high sensitivity to changes in the domestic growth rate also. Trade balance sensitivity to domestic market growth fraction set at 9%, 15% and 30% annual growth rate is presented in Figure 31. The trade balance improved with the increase in the domestic market growth fraction.

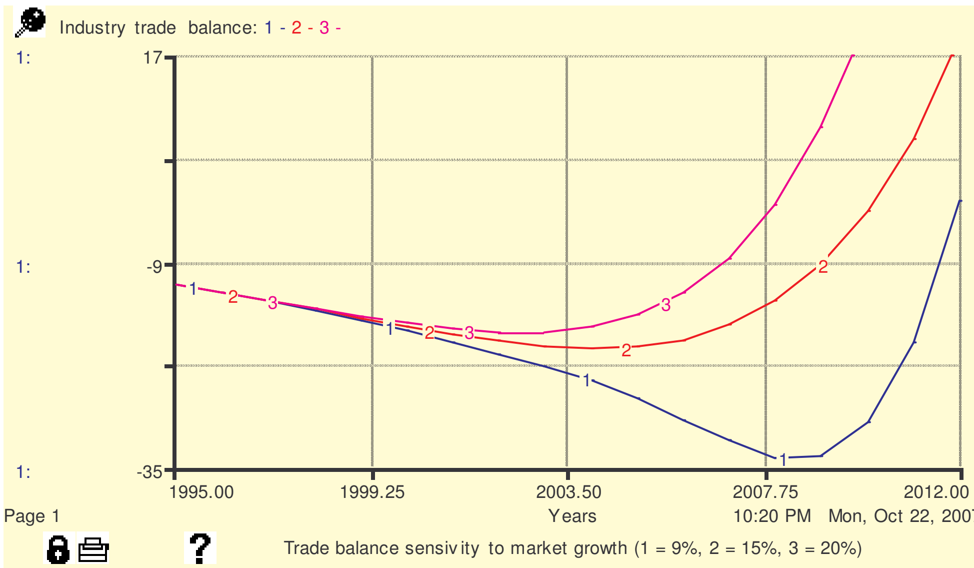


**Figure 31: Trade balance sensitivity to domestic market growth fraction**

Domestic market growth has an effect on industry investment via the production potential factor. Increase in the domestic market growth fraction induces higher levels of investment increasing the value of rebatable imports via the PAA rebate generation process. Increase in rebatable imports has a positive effect on overall industry imports and hence a negative effect on the industry trade balance. However, due to the model assumption that the impact of rebatable imports and domestic market depend on the ratio between the two, an increase domestic market growth fraction disproportionally increases the domestic market value relative to rebatable imports. Ultimately it lowers the import growth fraction, exerting a positive influence on the industry trade balance. This explains the overall upward shift in the industry trade balance trend as the domestic market growth fraction is adjusted upwards in Figure 31.

Trade balance sensitivity to low and high export growth rates is presented in Figure 32. Trade balance trend with export growth rates set at 15%, 20%, 24%, 27% and 30% respectively is shown. It is evident that the trend at 24% and 30% export growth rates is already substantially different to that at 27%, which was the reference mode export growth rate. As would be expected, trade balance was most sensitive to export growth rate. At very low levels of export growth rate, the trade deficit increased significantly, relative to the reference mode run. At high export growth rates, increase in trade deficit before start of decline was minimal. This could be understood in the context of the resultant high increase in industry exports at high export growth levels without commensurate increase in imports. The high sensitivity of industry trade balance to export growth rate points to the importance of accurate estimation of the rate, otherwise a small under- or overestimation could fundamentally change the model reference mode behaviour.

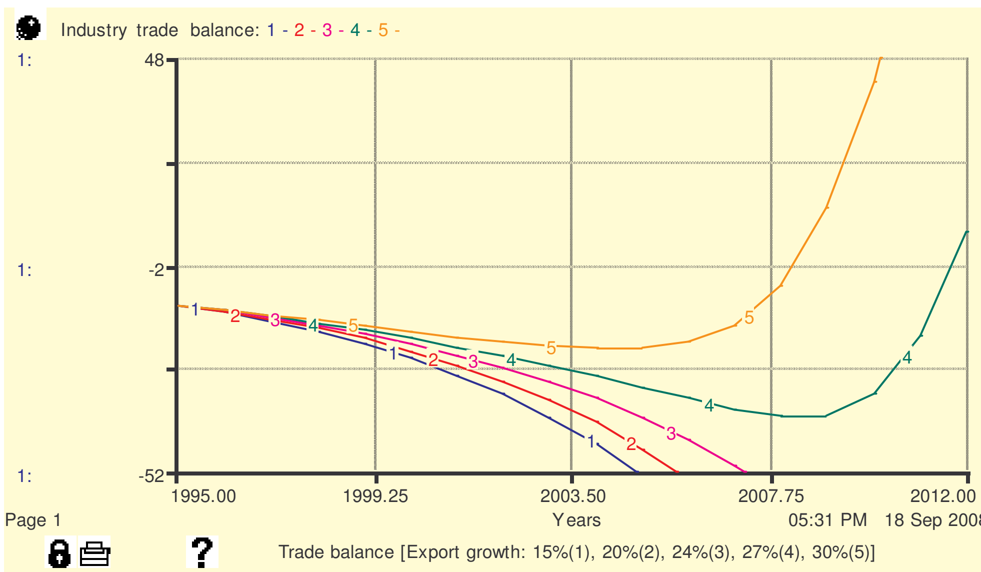


**Figure 32: Trade balance sensitivity to export growth fraction**

## 6.6 Exchange rates effect on industry trade balance

During discussions at the MIDP and with experts on the industry, exchange rate was pointed out as a significant determinant of imports growth. This was based on the understanding that domestic currency appreciation makes imports cheaper in the domestic market. Commodity market prices tend to rise easily when upward prices pressures are experienced in the market but the otherwise is not always true. Prices are often 'sticky' downwards when downward price pressures are experienced. As such, domestic currency appreciations tend to make importing more profitable as importers are likely to sell the 'cheaply' imported products at market prices prior to the currency appreciation. The suggestion, in this regard, was that changes in exchange rates should be accounted for in the model.

It was noted, however, that although changes in the exchange rates had a direct effect on profits, in the short term, this might not be significant enough to affect industry dynamics. Industry decisions on production and sales are often based on five to seven year business plans. It is very unlikely that industry will diverge from its business plan because of a short term disturbance like increase in profits due to a change in the exchange rate. Such a change in exchange rate is likely to have an effect on industry dynamics only if it is significant and persistent over time.

Another dimension of the exchange rate factor relate to its dual but opposite effect on costs and profits of domestic automotive productive activities. If the local currency appreciates, cost of imported components used in domestic manufacturing declines, but so does the revenue earned from exported products. The question therefore becomes that of comparing currency appreciation production cost reduction and the resultant decrease in export revenue per unit exported emanating from the same currency appreciation. This question was outside the scope of this study.

Again, although a change in exchange rate had the potential to affect the import growth fraction, the effect was not clear and could only come into play if it was persistent, unanticipated and drastic. As such the exchange rate effect on industry dynamics was not explicitly modelled. Model disaggregating, as proposed under the section for further investigation, would inevitably have to consider exchanges rates as one of the many factors, which have a potential to influence imports. Otherwise, historical data on the Rand-US dollar and Rand-Euro exchange rate indices versus automotive trade deficit index (Figure 33) is inconclusive in this regard.

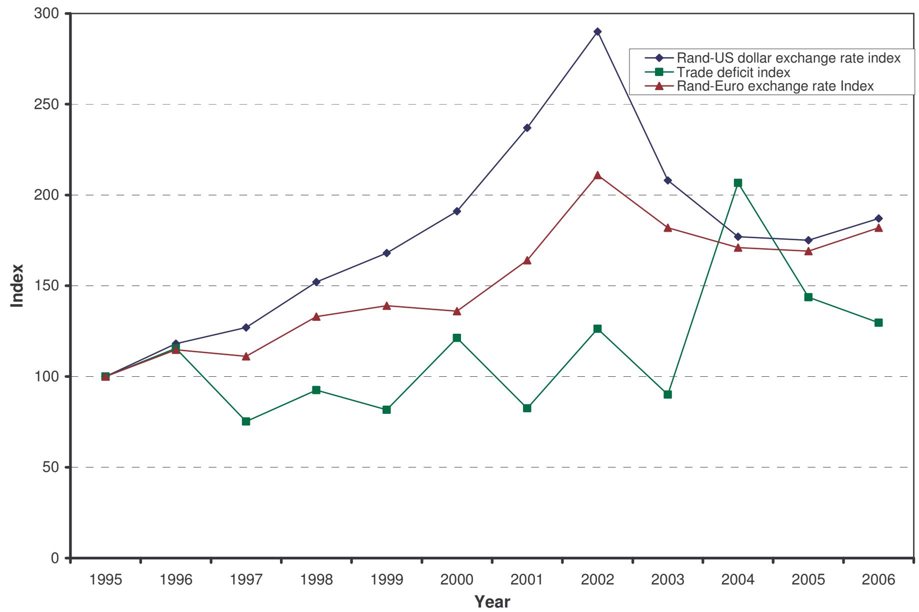


**Figure 33: Rand-US dollar/Rand-Euro exchange rate and automotive trade deficit indices**

Source: AIEC 2007

## 6.7 Synthesis

In formalising of an existing policy framework into a system dynamics model, the challenge is to capture the structural set-up of such a policy and relevant policy rules as carefully as possible. Expert opinion on the captured model structure serves the purpose of validating the model structure. Historical quantitative and qualitative data provides a useful base for model parameter estimation. Whereas expert opinion of the developed model structure is a major validation tool, explicit model behavioural tests tend to confirm general mathematical consistency of the model. Having gone through all these processes in developing the PAA-IEC-Trade balance model of the South African automotive industry, it was felt that the developed model could be used, with reasonable confidence, as a tool to test possible industry outcomes relating to policy decisions on PAA and IEC incentives of the MIDP. The model presented a useful scientific tool upon which policy decisions could be tested before they could be implemented. Most important, the model presented a formal policy framework that could be critiqued and objectively improved upon.