Luxembourg Income Study Working Paper Series

Working Paper No. 506

System-Based Analysis of Income Distribution Impacts on Mobility Behaviour

Michael Krail

November 2008

Luxembourg Income Study (LIS), asbl

System-Based Analysis of Income Distribution Impacts on Mobility Behaviour

Zur Erlangung des akademischen Grades eines Doktors der Wirtschaftswissenschaften
(Dr. rer. pol.)

der Fakultät für Wirtschaftswissenschaften der Universität Fridericiana Karlsruhe
(Technische Hochschule)

vorgelegte

Dissertation

von

Diplom-Wirtschaftsingenieur Michael Krail

Tag der mündlichen Prüfung:	....
Referent:	Prof. Dr. Werner Rothengatter
Korreferent:	....

Karlsruhe, im November 2008

Michael Krail
Institut für Wirtschaftspolitik und Wirtschaftsforschung (IWW)
Universität Karlsruhe (TH)
Telefon: +49-(0) 721 - 608 4371
E-Mail: krail@iww.uni-karlsruhe.de

Erklärung

Ich versichere wahrheitsgemäß, die Dissertation bis auf die in der Abhandlung angegebene Hilfe selbständig angefertigt, alle benutzten Hilfsmittel vollständig und genau angegeben und genau kenntlich gemacht zu haben, was aus Arbeiten anderer und aus eigenen Veröffentlichungen unverändert oder mit Abänderungen entnommen wurde.

Karlsruhe, den 31. Oktober 2008 ______________________________

(Unterschrift des Verfassers)

"System-Based Analysis of Income Distribution Impacts on Mobility Behaviour"

Since 2001, an increasing income inequality can be observed in most EU Member States. On aggregate level, this development is not reflected by statistics. They indicate growing average wages in real terms. Detailed statistics on average wages of different income classes reveal a tendency of diverging income distribution. Employees with low incomes even have to cope with decreasing wages in real terms. At the same time, energy prices have risen significantly due to exceeding peak oil and reinforcing oil scarcity. Considering these trends the question arises on how the income distribution in combination with increasing transport costs influences the mobility behaviour of persons in different income groups.

The thesis addresses this question by performing a system-based analysis of income distribution impacts on mobility behaviour. The integrated macroeconomic, transport and environmental model *ASTRA* is chosen as basic modelling framework for this work. The model has been developed since 1998 for the purpose of assessing transport strategies and is based on System Dynamics methodology. It consists of nine modules interacting with each other and covers all current 27 EU Member States plus Norway and Switzerland. The major benefit of applying the ASTRA model is determined by its integrative approach, considering feedback structures between economic, transport and environment systems.

Considering different explanatory approaches on income distribution a model is developed simulating the dynamics of personal income distribution in 18 European countries. Based on the requirements of the transport and vehicle fleet module, the population is allocated into five characteristic income groups. Finally, the model is validated for the period from 1990 to 2004 with micro-census data extracted from the *Luxemburg Income Study* database.

The transport model in ASTRA is derived from the classical four-stage passenger transport modelling approach. The thesis focuses on the income distribution impacts on the first modelling stage, the passenger trip generation. In a first step, available personal attributes in the travel survey *Mobility in Germany* are classified regarding their significance on the trip making behaviour. The result of the variance analysis determines the structure of the revised trip generation model. A comprehensive analysis of the travel survey enables the quantification of trip making behaviour for characteristic population segments in ASTRA. Additionally, the thesis considers impacts of income distribution on motorisation trends. They influence the third stage of the passenger transport model, the modal split. Furthermore, indirect effects on the technological composition of passenger car fleets in Europe are taken into account. For this purpose, the six alternative fuel technologies with the highest future potential are integrated in the car fleet model.

In order to demonstrate the impacts of income dynamics, two scenarios are assessed with the new ASTRA-S model and the results are compared with a baseline scenario until 2040. The first scenario excludes the new model developments. Simulation results show that the consideration of income distribution increases the level of detail significantly so that an overestimation of passenger transport performance and motorisation can be avoided. The second scenario is a combined policy and technology scenario. It highlights the model capabilities in terms of sustainability impact assessment. The scenario addresses the potential of a carbon tax to support hydrogen as future clean energy source for transportation.

The thesis is supervised by Prof. Dr. Werner Rothengatter.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

ANOVA	Analysis of variance
ASTRA	Assessment of Transport Strategies
ASTRA-S	New ASTRA model version
AUT	Austria
BAU	Business-as-usual scenario
BIO	Bioethanol cars
BLX	Belgium and Luxemburg
BLG	Bulgaria
BU	Business trips: category of passenger trip purposes in ASTRA
CBA	Cost-Benefit Analysis
CEC	Commission of the European Communities
CHE	Switzerland
CLIO	Classification and nomenclature of input-output
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
CSE	Cold start emissions
CYP	Cyprus
CZE	Czech Republic
DB	Distance band. Modelling and analysis of transport reactions is focused on such DBs.
DGTREN	Directorate General Energy and Transport
DNK	Denmark
DPC	Diesel passenger cars
E85	Bioethanol E85
ELC	Electric cars
ENV	Environment module
ESP	Spain
EST	Estonia
EU27	European Union Member States since 2007
EU27+2	European Union Member States since 2007 plus Norway and Switzerland
FOT	Foreign trade module
FIN	Finland
FPE	Fuel production emissions
FRA	France
FTE	Full-time equivalent refers to part-time and FTE employment
GBR	Great-Britain
GC	Generalised cost
GDP	Gross domestic product
GER	Germany
GPC	Gasoline passenger cars
GRC	Greece
GVA	Gross value-added
H2	Hydrogen cars
HB	Home-based trips
HBEFA	Handbook of emission factors
HDA	High density areas: category of functional zones in ASTRA

HDV	Heavy duty vehicles; gross vehicle weight above 3.5 tons
HOT	Hot emissions
HUN	Hungary
HYB	Hybrid cars
INC	Income group
INF	Infrastructure module
IRL	Ireland
ISCED	International Standard Classification of Education of the United Nations
ITA	Italy
KONTIV	Mobility in Germany
LAT	Latvia
LC	Local (distances below 3.2 km)
LDA	Low density area: category of functional zones in ASTRA
LDV	Light duty vehicles; gross vehicle weight below 3.5 tons
LG	Passengers distance band: Long (distances > 160 km)
LGD	Freight distance band: Long distance (distances > 700 km)
LIS	Luxembourg Income Study
LOC	Local (trips shorter than 50 km)
LPG	Liquified petroleum gas
LTU	Lithuania
MAC	Macro-economic module
MCA	Multiple classification analysis
MD	Passengers distance band: Medium (distances => 40 and 160 km)
MDA	Medium density area: category of functional zones in ASTRA
MED	Freight distance band: Medium (distances => 150 and 700 km)
MIT	Massachusetts Institute of Technology
MLT	Malta
MPA	Metropolitan area: category of functional zones in ASTRA
MOP	German Mobility Panel
NACE	General industrial classification of economic activities within the European communities
NHB	Non-home-based trips
NLD	The Netherlands
NOR	Norway
NO_2	Nitrogen dioxide
NTS	National Travel Survey
OD	Origin-destination, usually refers to transport OD-flows or OD-matrices
OECD	Organisation for economic co-operation and development
OEM	Original equipment manufacturer
PE	Personal trips: category of passenger trip purposes in ASTRA
pkm	Passenger-kilometres
PM_{10}	Particulate matter sometimes referring to particles of certain size e.g. particles with a diameter of less than 10 µm (PM10)
PO	Potential output
POL	Poland
POLES	Energy demand and supply model
POP	Population module
PRT	Portugal

REG	Freight distance band: Regional (distances => 50 and < 150 km)
REM	Regional economic module
ROM	Romania
RoW	Rest-of-the-world
SDM	System dynamics model
SLO	Slovenia
SMCP	Social marginal cost pricing
ST	Passengers distance band: Short (distances => 8 and < 40 km)
StaBA	Statistisches Bundesamt
SVK	Slovakia
SWE	Sweden
TFP	Total factor productivity
tkm	Ton kilometres
TO	Tourism trips: category of passenger trip purposes in ASTRA
TP	Trip purpose
TRA	Transport module
UN	United Nations
UNIDO	United Nations Industrial Development Organizations
VFT	Vehicle fleet module
VKT	Vehicle-km travelled
VOC	Volatile organic compounds
VPE	Vehicle production emissions
VS	Very short (distances => 3.2 and < 8 km)
WEM	Welfare measurement module
VoT	Value-of-time
SD	System Dynamics

1 Introduction

One of the most important challenges of mankind in the 21st century is to attenuate global warming and climate change process. According to a representative TNS-Emnid survey of the year 2007 on behalf of GREENPEACE (2007), about 85 % of the German population considers climate change as a problem that will threaten its future life significantly. Despite this cognition, only a small percentage of the population changes its behaviour in an appropriate and sustainable way. Unfortunately, significant behavioural changes occur only, when people are directly affected by negative impacts. An alternative is the initiation of behavioural changes by policy actions before significant negative impacts occur. In order to determine efficient policy actions for the realisation of future targets, future impacts of policies have to be assessed. Models simplifying real world systems can be regarded as suitable tools to carry out this responsible task. With growing awareness of the utility of simulation models, several modelling methodologies were developed.

In the mid of the 20th century, the scientist BERTALANFFY (1968) recognised that *"the whole is more than the sum of its fractions"*. Influenced by emerging system thinking in many disciplines of science, he determined the *Systems Theory*. Principles of this theory were adopted by FORRESTER (1962). Based on the observation that social systems consist of interacting information feedback systems of higher order, incorporating non-linearity, he developed the *System Dynamics* methodology. After first applications of System Dynamics methodology leading to urban models, the well-known World model was designed to project world economy trends for the Club of Rome.

As all systems consist of feedback structures which determine by their interaction with one another the dynamics of the system, System Dynamics is chosen as best methodology to implement an integrated macroeconomic, transport and environment model. The main objective of the model which has been developed since 1998 in cooperation between the Institute for Economic Policy Research (IWW) at the University Karlsruhe (TH), Trasporti e Territorio (TRT) in Milan and Fraunhofer-Institute for Systems and Innovation Research (ISI), is the assessment of transport strategies. The name of the model is derived from the abbreviation of the main objective: ASTRA. Since 1998, ASTRA has been further developed and simulates macroeconomic, transport and environmental development of all current 27 member states of the European Union plus Norway and Switzerland. Several studies have been carried out with this System Dynamics model, in which ASTRA was applied as tool for assessing impacts of transport policy, climate change strategies and technological scenarios. As opposed to static modelling approaches, the underlying System Dynamics methodology enables the analysis of the whole time path until the final simulation year 2040.

The experiences which could be gained during several impact assessment studies with the ASTRA model revealed the strengths of the tool as well as its weaknesses. Besides macroeconomic, transport and environmental influence of transport policies, equality issues of policies appeared on public agenda. The only social indicator in ASTRA which could be derived for a further qualitative analysis of social impacts outside ASTRA was employment per economic sector respectively unemployment. Policy impacts on income inequality and interpretation of the capability to cope with financial burdens caused by transport policies could not be answered. Hence, the third dimension of sustainability, the social component, was missing and an entire quantitative sustainability impact assessment of transport strategies was not possible with ASTRA.

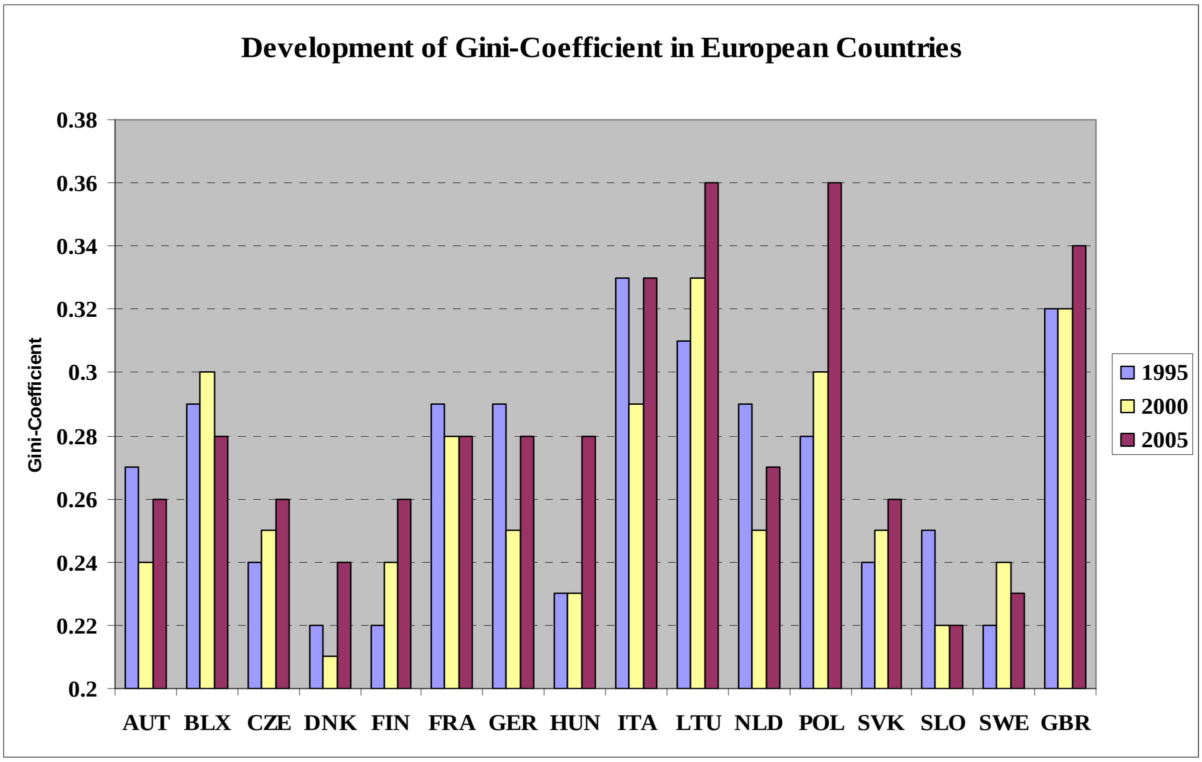

Figure 1-1: Development of Gini-Coefficient in Europe extracted from EUROSTAT (2008a)

A second weak point in ASTRA became obvious during ongoing discussions about diverging income trends between employees with low and employees with high income in many European countries. Statistics confirm declining wages in real terms for persons in low income classes. This trend is noticed in many European countries. As opposed to this observation, income in real terms of persons in medium to high income classes are characterised by continuous high growth rates. The resulting rising income inequality can be followed by the development of the Gini-Coefficient in Figure 1-1. The Gini-Coefficient is a popular indicator for income inequality. Growing income inequality is indicated by higher Gini-Coefficient. Especially in the period between 2000 and 2005, income inequality increases in most European countries. Increasing income inequality can be observed only on the micro-level. On a macro-level, the aggregated average income per employee does not reflect increasing income inequality neither the trends in the lower income classes. Statistical data confirms that the average income per employee in real terms is in most European countries increasing in the period between 1995 and 2005, mainly caused by high income growth of medium to high income classes.

The development of disposable income of private households was considered as one of the major drivers of motorisation growth. As a result of the increment of average income, ASTRA overestimated future motorisation in some countries in EU27. Even the consideration of negative impacts like fuel cost increase could not limit the projection in a sufficient way, such that exogenous upper limits were defined, based on expert judgements. Due to the implemented feedback structures in ASTRA, impacts of a probable overestimation of car-ownership induced, among others, higher economic growth and growing passenger transport performance.

Having in mind the increasing income inequality and decreasing wages in low income classes, the question raises, if these trends impact the passenger transport mobility besides the car purchase behaviour. Analysis of European travel surveys can give an answer to this question, as at least some travel surveys query income information from its panel members. Those surveys indicate the trip making behaviour of persons in different income classes as well as average trip distances. Travel surveys confirm that the number of trips, as well as the trip distance depends on the level of income of a person. Therefore, at least two stages of the ASTRA passenger transport model which is derived from the classical four-stage transport model (ORTÚZAR/WILLUMSEN 1990) are affected by income dynamics: the first stage consisting of trip generation and the second stage, the distribution of trips on all possible destinations.

Besides the lack of information about impacts on and of income distribution in ASTRA, another essential weak point emerged in the last years. The vehicle fleet models in ASTRA are responsible for the simulation of prospective vehicle fleet composition in terms of engine technology, size and emission standard. This technological information is required as an input in the environmental module. Transport-related emissions can only be assessed, as long as the technological composition of the car fleet together with passenger transport performance can be projected. Not only experts foresee that growing scarcity of mineral oil and increasing prices will lead to technological changes in the transport sector. Thus, ASTRA should be able to simulate the diffusion of alternative car technologies into the EU27 car fleets. Otherwise, the quality of climate policy impact assessment results, simulated with the ASTRA model, does not suffice for decision support of policy makers.

Derived from this cognition, the objectives of this thesis are elaborated and defined in the following. The introduction concludes with a description of the course of investigation for fulfilling these objectives.

1.1 Objectives

The main objective of this thesis is the integration of a model which will simulate income mobility respectively income distribution in EU27 member states into the System Dynamics model ASTRA. The heterogeneous information about income distribution in EU27 provided by the new income distribution model will be used as input in two other ASTRA modules. The two modules are on the one hand the first stage of the four stage transport model, the passenger trip generation model, and on the hand the car registration model which simulates the development of motorisation in EU27. In the latter, the number of potential car purchasers, estimated on the basis of detailed income information, will be applied in order to prevent an overestimation of motorisation. In the trip generation model, the new input is supposed to improve the level of detail, as the population will be differentiated into more segments with certain combination of attributes than in the previous ASTRA model. Hence, the generation of the number of trips that start in a certain zone for a set of trip purposes will be further differentiated. The consideration of information about income distribution as input for the trip distribution model could not be realised in this thesis. Therefore, the analysis of income distribution impacts with ASTRA focuses on influences on trip-making behaviour. The foreseen ASTRA modifications in combination with the development of an income distribution model will increase the level of detail of the model which improves the projections of transport policies and climate change strategies impacts. Last but not least, the modifications enable a complete sustainability impact assessment covering significant indicators of all three dimensions of sustainability: economy, environment and society. Impacts of income distribution on trip generation will be demonstrated in terms of average number of trips per population segment based on travel survey analysis as well as via comparison between ex-ante ASTRA and new ASTRA results.

In order to perform a comprehensive assessment of transport, technological and climate change policy impacts with ASTRA, a second objective consists in the integration of alternative car technologies in the ASTRA car fleet model. A car technology model simulating the probability that a car purchaser decides to purchase a car with a certain engine technology and engine size is enhanced by the most promising alternative car technologies. This includes technologies like hydrogen which are not yet on the market as well as rather old alternative car technologies like Liquefied Petroleum Gas cars (LPG). Finally, the structure of the EU27 car fleets is determined by the motorisation development, computed in the car registration model, and the probability of technology choice simulated in the car technology model. Income distribution impacts constitute important inputs for the simulation of motorisation as well as for the choice of a certain engine technology and car size. Existing surveys among car purchasers do not take into account the income of the respondents. Hence, no empirical study is available that provides the baseline for a quantification of income distribution impacts on engine technology and size affinity. Nevertheless, another objective of this thesis is to develop a car technology choice model that can consider income distribution impacts if further research on this link will be carried out.

Due to the difference between the previous ASTRA car model in which the car purchaser could decide between technologies that are presently available on the market and the new ASTRA car model which considers new future technologies, the structure of the model has to be changed completely. Furthermore, the ASTRA environmental module requires an update. New alternative car technologies and emission and fuel consumption factors need to be added in order to enable the simulation of transport-related emissions.

1.2 Course of Investigation

In order to put the presented objectives into action the thesis starts with an overview of the underlying System Dynamics methodology. The historical development of *Systems Theory*, *Cybernetics* and finally *System Dynamics* in combination with the principles of the theories aims to demonstrate the benefits of the methodology for the purpose of this thesis. Additionally, the single modelling steps that are necessary to generate a System Dynamics model are explained.

In the following section the ex-ante ASTRA model, in which all new models and model modifications will be integrated will be presented to the reader. Starting with an overview of the interaction of the nine ASTRA modules, the characteristics, structure and main outputs of the single modules will be depicted in a sequence. The major purpose of this section is the differentiation between the ex-ante ASTRA and the new ASTRA model. Additionally, the capabilities and constraints of the ASTRA model are being clarified.

The following section is subdivided according to the two main objectives of this thesis. The major part describes the development of the new established income distribution model and the modification of passenger trip generation and car registration model. The smaller part presents a description of the implementation of alternative fuel cars in the car technology model. The complete model description is introduced by a chapter providing an overview of the coherence of model developments and modifications. The new developed household model which is designed to provide valuable endogenous information for the simulation of income distribution is presented as first new model. After an introduction in income in economics and definition of the most important income terms, a brief overview of statistical methods is depicted. A detailed description of existing theoretical explanatory approaches of income distribution is concluded by a demonstration of characteristics of existing income distribution models. The main objective of the theoretical introduction is to provide the background for the following description of the implemented income distribution model. At first the process of determination of a model framework is deduced from the requirements of the trip generation and car registration model. After a detailed analysis of available income distribution data, the final structure for the model is fixed. The final step in the model development, the identification and classification of possible drivers of income distribution is presented together with the way of integrating the impacts in the model.

The main objective of the next section is the description of the modified trip generation model and the travel survey analysis of impacts of income distribution on mobility. This part of the thesis begins with an overview of the theory of trip generation and possible approaches. It demonstrates the state-of-the-art approach which is adopted in the ASTRA trip generation model. In order to quantify the impacts of different population segments considering income distribution, available travel surveys are presented. The survey that fulfils the requirements for this thesis in the best way is chosen and analysed in detail. In order to determine most significant attributes of persons concerning the trip-making behaviour the analysis of variance is applied and described. The result of this analysis provides the necessary information for the final extraction and modification of average trip rates per population segment.

The following chapter describes the integration of income distribution information into the car registration model. The estimation of a saturation effect providing a constraint to motorisation development is presented. For the purpose of the second part of this section, the process of integration of six further alternative car technologies into the car technology choice model is depicted. The required implementation of emission factors in the environment model as well as the enhancement by two further pollutants concludes the description of model developments and modifications for this thesis. Finally, the calibration process of the ASTRA model is pictured.

The main objective of the following section is the presentation and interpretation of simulation results. Therefore, results of two scenarios are presented and compared with a baseline case. After the definition of assumptions of the baseline scenario, the main results are illustrated. In the following, one scenario that excludes the new model developments and a policy scenario which consists of a carbon tax introduction for passenger transport in order to support hydrogen as future main car technology are analysed.

Finally, the model developments will be reviewed and an outlook on future research activities will be presented.

2 System Dynamics

In the year 1940 the dream of the citizens of Tacoma, Washington State, became reality. The construction of a suspension bridge with 853 meters longest span over the waters of Puget Sound linking the spectacular, thinly settled Olympic Peninsula with the Washington mainland was finished. The prestigious designer of the bridge, Leon Moisseiff, proposed to construct the bridge with significantly shallower girders due to the expected low traffic volume over the bridge in order to reduce construction costs. Soon after the opening, the Tacoma Narrows Bridge itself became the main attraction caused by the low weight, the specific slender and aerodynamically adverse profile of the bridge. The bridge began to resonate even if the wind was not too strong.

Initiated by a phenomenon called Kármán vortex[1] the resonance frequency or in other words a dynamic feedback process was responsible for the swinging of the bridge. The appearance of this phenomenon attracted many pedestrians and car drivers who crossed the swinging bridge just to have the specific roller coaster feeling. The transverse resonance meant that drivers saw cars approaching from the other direction disappear into valleys that were dynamically appearing and disappearing. Nevertheless, the Galloping Gertie – as the bridge was affectionately called – was kept open because the mass of the bridge was considered sufficient to keep it structurally sound. In November 1940 an unforeseen incident initiated the final collapse of the Tacoma Narrows Bridge. A holding cable tore and led to a never-before-seen twisting mode of the bridge. The amplitude of the bridge increased due to this torsional twisting. Finally, this reinforcing feedback loop of a dynamic system led to the collapse of the suspension bridge and the death of a dog sitting in the car of a journalist reported by TIME (1940).

Bearing the aerodynamics of the bridge in mind during the planning stage, would have avoided the collapse. The accident induced that since then each building and bridge is planned as a matter of course under consideration of dynamic systems interacting with respectively within a building. Since the middle of the 20th century civil engineering is only one out of many disciplines that is using systems thinking and regarding the development of systems over time. The scientific field of Systems Theory covers all these approaches. The following chapters describe the development of Systems Theory, the characteristics of systems and the simulation of systems with the System Dynamics methodology.

2.1 Systems Theory and Cybernetics

In the mid of the 20th century, Ludwig von Bertalanffy was the first scientist attempting to develop a theory of systems. The biologist discovered that an organism can not only be explained by elemental breakdown and understanding the processes within each fraction of the organism. He recognised that “the whole is more than the sum of its fractions” (BERTALANFFY 1968, p.12) which is originally a statement made by the Greek philosopher Aristotle long before Christ.

[1] KÁRMÁN (1963) vortex street is a phenomenon in fluid mechanics. Unsteady separation of flow over bodies is responsible for repeating patterns of swirling vortices. This phenomenon was observed for the first time by the fluid dynamicist Theodore von Kármán.

Inspired by the established systems thinking in physics and biology, Bertalanffy determined the *General Systems Theory*. He defined the search for common principles in physical, biological and social systems as the main objective of his theory:

> *"Thus, there exist models, principles, and laws that apply to generalised systems or their subclasses, irrespective of their particular kind, the nature of their component elements, and the relationships or "forces" between them. It seems legitimate to ask for a theory, not of systems of a more or less special kind, but of universal principles applying to systems in general."* (BERTALANFFY 1968, p.32)

In parallel Norbert Wiener, a scientist from the engineering field, focussed on research on control and communication in human beings and machines (WIENER 1961). In the context of his studies Wiener determined the expression *Cybernetics* in the year 1947 defining it as the study of feedback mechanisms, black boxes and derived concepts like communication and control in organisms, machines and organisations. Besides Wiener and many other scientists of different disciplines, the American neurophysiologist Warren S. McCulloch and the English psychiatrist W. Ross Ashby established Cybernetics as discipline. McCulloch worked primarily on neural network modelling while Ashby addressed the analysis of complex systems (ASHBY 1974).

Since the beginning the terms Systems Theory and Cybernetics were mainly used as synonyms. Today Cybernetics is seen as a branch of Systems Theory denoting a subset of the class of general systems that include feedback loops. As a whole, Systems Theory covers different, interdisciplinary approaches for explaining real world problems with the help of structure and behaviour of systems.

2.2 System Analysis

In the contemporary literature a multitude of definitions of the term *system* exist. Those definitions can be categorised and distinguished by their basic concept (BUTEWEG 1988, p.19f). Some definitions focus on the function of a system. These concepts are mainly followed in the field of electrical engineering, where the effects of a system are considered as most significant whereas the functioning of the system is not. ASHBY (1974, p. 132 ff) denotes such systems as *black boxes*. On the other hand many disciplines are interested in the reason for certain system behaviours and the understanding of the structure of a system. Bertalanffy defined a system *"as a complex of interacting elements. Interaction means that elements, p, stand in relations, R, so that the behaviour of an element p in R is different from its behaviour in another relation R"* (BERTALANFFY 1968, p.55). Another suitable description could be to determine a system as "*a set of interrelated elements, each of which is related directly or indirectly to every other element, and no subset of which is unrelated to any other subset"* (ACKOFF/EMERY 1972, p.18).

In other words a system can be defined as a set of elements which are interacting with and influencing each other. Distinct relations connect the elements of a system. The number of connections between the system and its environment are limited and the separation of the system from its environment is called system border. Systems can consist of several sub-systems which are all individual systems. The structure of a system is determined by the relations between its elements. The state of the system elements is influenced over time by the interaction of elements. Hence, the behaviour of a system can be studied by observing the structure of a system.

Mathematically a system S can be described as a set of elements with relations in the following way:

$$\boldsymbol{S = (C,R)} \qquad \textbf{eq. 2-1}$$

where: S = system
C = set of elements
R = set of relations per element

The main objective of system analysis is to observe the interaction between system elements in order to understand the behaviour and change of complex systems over time. The interaction of the system is more important than the single elements of the system. Connections between the system and its environment are treated in a different way. System analysis proposes that each exogenous variable which affects the system is not or only negligible impacted by the system itself. The determination of system borders and exogenous variables beyond that border is a significant milestone in systems analysis and modelling. This suggestion that the system environment is not influenced by the system itself constitutes an important rule for system analysis. Figure 2-1 illustrates the structure of a system and its main elements in a descriptive way.

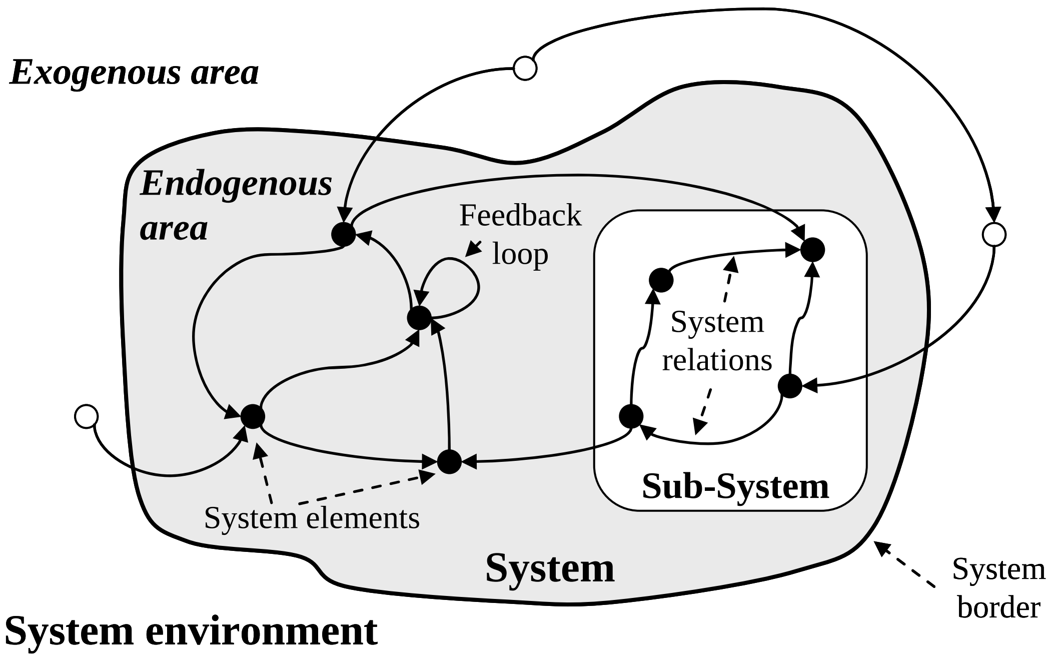

Figure 2-1: Structure of Systems

The definition of the system is mainly influenced by the objective of the modeller. Based on these objectives the modeller distinguishes between endogenous elements as a part of the system and exogenous elements differentiated from the system via the system border. In the initial phase of model development a causal analysis is performed in which the modeller should identify all relations of the system and its elements. Based on the structure of interrelations between elements a feedback structure inherent to the system is developed. A sequence of relations beginning at the system element N leading via other system elements and finally reaching the same element N again is called a feedback loop. Feedback loops can be considered as the most important characteristics of complex systems concerning the system behaviour. Sterman stated that *"all systems, no matter how complex, consist of networks of positive and negative feedbacks, and all dynamics arise from the interaction of these loops with one another"* (STERMAN 2000, p.13).

Most often, the sequence of relations leading from one element back to the same element is characterised by a time structure. This means that the starting point at one element feeding back to this element does not happen at the same point of time. BOSSEL (1994) differentiates between two categories of feedback loops: negative and positive feedback loops.

A feedback loop that is aiming at a target is called negative feedback loop. These kinds of feedback loop tend to re-establish equilibrium in systems. A system with a negative feedback loop responds on deviations from the original target by counteracting this diverging trend. Well-known examples for negative feedback loops are the controlling of temperature in a room with a thermostat, phase-locked loops in radios and computers or hormonal regulations in human beings. Temperature regulation in thermostats demonstrates in an easy way the process in a negative feedback loop: After the determination of a desired temperature by the use, the thermostat measures the actual temperature and activates the heating when the current temperature is lower than the desired temperature until the difference between envisaged and actual temperature is zero.

Feedback loops are called positive feedback loops when the change of a system element induces changes of other elements that finally reinforce the original change of the first element. Positive feedback loops introduce processes that accelerate growth or decline of system elements. Consequently, systems that consist only of positive feedback loops will crash. Descriptive examples for positive feedback loops are the interrelationship between wages and prices better known as inflation-spiral or for instance the audio feedback between loudspeakers and microphones. The familiar squeal occurs when sound from loudspeakers enters an adverse located microphone. The sound is amplified and gets louder and louder.

Feedback control as a discipline can be assigned to the engineering field. As such, its progress is closely linked to many problems of everyday life that occurred and could be solved during any phase of human history. MAYR (1970) and in the following FULLER (1976) describe the long history of automatic respectively feedback control. Already in the 3rd century before Christ the Greek inventor Ktesbios, well-known as the “father of pneumatics”, created an elaborate mechanised water-clock[2] based on a flow regulator. The construction was rather simple with a sophisticated feedback control mechanism: A swimmer in a vessel regulates the inflow of water from the top and the outflow of water on the ground. The swimmer reacts on the water level on the ground and reduces the inflow of water automatically. In this early stage the applications working with feedback concepts concentrated on the engineering disciplines. Additionally, MAYR (1971) describes applications of feedback mechanisms also in classical economics like in the magnum opus of SMITH (1776). The most popular example of a feedback mechanism in Smiths theories is the general system of supply and demand with its dependencies. In this feedback system the new input is determined by the difference between demand and supply leading to changes of the market price. Producers compare this price with the natural price and decide on the basis of the difference between the two prices

[2] COWAN (1958) writes about water-clock flow regulators appearing in China already in 4000 BC.

about changing supply. This change of supply closes the feedback loop by influencing the new input into the system.

A lesson learnt from the various examples is that feedback loops appear in every discipline, in engineering, physical as well as social systems to which economic systems belong. The only difference between the feedbacks in these three disciplines is constituted by the complexity of the systems themselves and their feedbacks. Structures of physical, engineering and social systems are constrained by the laws of nature. In contrast to physical and engineering, social systems are able to adapt their structure and relations more easily. Hence, social systems are considered to be far more complex than other systems. Based on this awareness the major challenge in understanding systems is to reduce the complexity of these systems. Simplifying real systems presumes that the most important characteristics of a system, the system behaviour can be extracted from the real system. The development of a simplified representation of a real system is called model and the development stage model design.

BOSSEL (1994) distinguishes between two modelling strategies:

- statistical descriptive or behavioural modelling and
- explanatory or real structure modelling.

The first modelling strategy implies the analysis of dependency of input and output and the behaviour of a system via regression analysis. This strategy conceals the disadvantage that the actual interrelationships within a system might not necessarily be considered. In this case the modeller understands the system as a black box. The second strategy, explanatory respectively real structure modelling is in terms of comprehension of overall context of a system the favourable strategy. Forecasts and estimations on future effects that were not observed in the past are only possible and reliable with this modelling strategy. The represented system is no longer a black box.

BOSSEL (1994) illustrates the necessary steps to illustrate a system within a model. At first a mental model of the real system in an abstract form should be built. The mental modelling stage is strongly affected by subconscious human perception. The major task of the following step is to transform the abstract model in a system model. The modeller has to take into account that the resulting system model should be less complex that the abstract model. The resulting system model can be classified in four categories:

- verbal or formal models,
- physical or abstract models,
- static or dynamic models and
- linear or non-linear models.

The following chapter highlights the development, main principles and characteristics of System Dynamics methodology. Regarding the described system model characteristics System Dynamics models constitute formal, abstract, dynamic and non-linear models.

2.3 System Dynamics Modelling

The System Dynamics Society defines System Dynamics as *“a methodology for studying and managing complex feedback systems, such as one finds in business and other social systems”* (SDS 2008). System Dynamics is an aspect of System Theory which is strongly related to the principles of System Thinking. The difference between the terms will be described after presenting the development of System Dynamics methodology from the hour of birth until today.

Studying the history and development of System Dynamics methodology the name of one scientist is referenced in almost every single scientific article: Jay W. Forrester. The sentence *“everything I have ever done has converged to become system dynamics”* (FORRESTER 1989) with regard to the origin of Forrester, he grew up on a farm in Nebraska, arouses the suspicion that the principles of System Dynamics were born in his daily life.

In fact, the hour of birth of System Dynamics can be assigned to studies on important characteristics of the behaviour of social systems, like the strong oscillations in the production of household appliances due to work-load at General Electric Company or the investigation of Boston city development (FORRESTER 1995). Forrester analysed these systems and found out that short-term solutions for problems emerging in these systems prove satisfactory only on the long run, while being even adverse on the short run. The counterintuitive behaviour of these systems brought Forrester to the conclusion that successful acting in systems on the long-term might presuppose accepting worse effects on the short-term. He gathered out of the observed behaviour that social systems are information feedback systems of higher order incorporating non-linearity. Furthermore he concluded that our way of thinking concentrates mainly on first order (negative) feedback loops. A simple example that could clarify the meaning might be the try to warm up hands at an oven. If it is too hot and one burns his fingers, he pulls them straight away from the oven. Only the variation of one level variable, the distance between oven and hand, directly affects the temperature at the fingers. Contrary to this example, cause (represented by the oven heat) and effect (represented by warm fingers) may have a bigger distance from each other in social systems in time as well as in space. In-between there are a lot of influencing factors impacted by the system itself and delays in time. Forrester considers the time delays to be significant for the behaviour of social systems as "...*without delays our systems would not exhibit their usual characteristics toward instability*..." (FORRESTER 1962, p62).

The urban dynamics model of FORRESTER (1969) investigating the social problems in the city of Boston attracted the attention of urban planers world-wide. Among them was one of the founders of the Club of Rome. In several meetings with Club of Rome members Forrester discussed issues surrounding global sustainability. In the course of discussions, the most prominent application, the World model was developed by FORRESTER (1973). The main objective of the model was to provide projections of world economy trends. The model simulated the development of five major indicators until the year 2100: population, industrial production, food, natural resources and pollution. In the following a former student of Forrester, Dennis Meadows, enhanced the original World model. The spectacular simulation results which projected a break-down of food supply and scarcity of natural resources were analysed in the well-known book of MEADOWS (1972) “*Limits to Growth”*. KUPPER (1972) commented the depicted results as *“computer-made vision of apocalypse”*. Reviewers find fault with the extrapolation of trends without any consideration of technological, economic and political adaptation. The discussions are still in progress, if recent scarcity of food, mineral oil and gas and enforcing climate change and its consequences are heralds of the originally projected development. Dennis Meadows and his wife Donella updated the World model in regular steps such that the most recent model results were published in 2006 (MEADOWS 2006).

Having in mind these characteristics of social systems FORRESTER developed the theory and methodology of System Dynamics. He recognised that the development of the methodology strongly depends on the output of three other research fields followed by well-known researchers at MIT: the Cybernetics theory developed by Wiener, the study of Vannevar Bush on differential analysers and the feedback control theory mainly associated to Harold Hazen and Gordon Brown. Based on this knowledge Forrester identified the following six basic requirements of System Dynamics methodology:

- The theory of information feedback systems applied to social systems,
- the mathematics of differential analysis respectively difference equation analysis,
- decision theory allowing the description of development paths over time,
- a mental modelling approach enabling the design of complex social systems,
- digital computing in order to be able to deal with the large number of calculations and
- a graphical concept that should be able to illustrate systems of feedback loops.

Coming back to the main steps in developing a System Dynamics model, the first step is constituted by the definition of system borders and based on this the assignment of elements to endogenous and exogenous area.

Donella H. Meadows stated that "*the idea of two-way causation or feedback*" (MEADOWS 1980 p.31) is the main step to understand the structure of systems according to the System Dynamics methodology. Hence, the second step in the construction of a System Dynamics model should be the identification and description of feedback loops in the system. The best method to illustrate the connections between system elements and to recognise feedback loops is to design a causal diagram. The major advantage of causal diagrams is their power to clarify system structures to the modellers on the one hand and decision-makers or analysts on the other hand. The simple design of causal diagrams consisting out of variables linked by arrows with a certain polarity and a loop identifier makes these diagrams easy to understand even if the viewer is not used to them. Figure 2-2 pictures the elements of causal diagrams in an example derived from BOSSEL (1994) representing a simplified world model. Focussing on one of the illustrated relations, Bossel set the hypothesis that increasing environmental burden is decreasing the population number. This negative feedback is represented via an arrow pointing from environmental burden to population and the minus sign standing for the negative polarity of the relation.

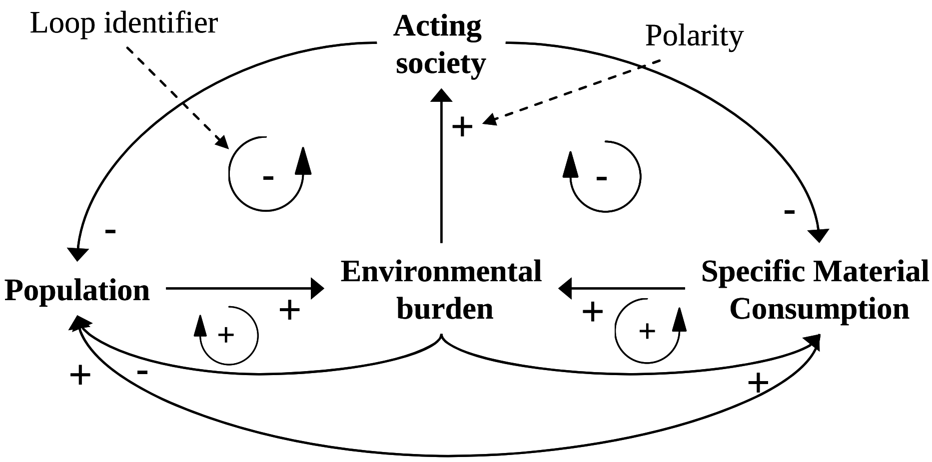

Figure 2-2: Elements of Causal Loop Diagrams

In order to determine the connections between elements and their polarity of such an abstract System Dynamics model, the modeller has to hypothesise on the relationships based on existing theories, empirical findings from statistics, surveys or other observations, expert judgements or other mental models. After the completion of a causal diagram of the system the identified connections and interrelationships have to be transformed into a System Dynamics model. This translation process requires a formalisation of all elements and relationships of the causal diagram.

The form of System Dynamics models defined by FORRESTER (1969) in a nomenclature is rather simple as each System Dynamics model consists of only five elements: level variables (levels) and flow variables (rates) are the main elements building the feedback loops. Additionally parameters (constants), exogenous and auxiliary variables are completing the list of elements. Level variables constitute the most important elements of a system. The development of a level variable over time represents and shows the state and the behaviour of a system. System Dynamics models compute level variables as integration over time. At the beginning of a simulation run the model requires initial values of levels. Level variables change during a simulation according to all flow variables linked with the level variable. Flow variables occur as inflows to or outflows from a level. Therefore, the balance between inflow and outflow and the initial value of the level variable are determining the future value of the level variable. Flow variables can simulate decisions implemented by the modeller. In other words a level variable can be considered as a reservoir that is filled and depleted by one or more flow variables. System Dynamics models compute the new state of a level variable by adding or subtracting the changes that occur during the next time step. Mathematically, the following equation[3] describes this process:

$$L(t) = L(t - dt) + (IR(t) - OR(t)) * dt$$ **eq. 2-2**

where:
- L = level variable [units]
- dt = time interval between current and previous time [time]
- IR = flow variable representing inflow rate [units/time]
- OR = flow variable representing outflow rate [units/time]
- t = current point of time

[3] As all dynamic equations contain time t as variable, time t will not be mentioned in the following descriptions of equations in this thesis.

Equations of level variables are in mathematical sense difference equations derived from corresponding differential equations. They look in the following way:

$$L(t) = L_0 + \int_0^t \left[IR(\tau) - OR(\tau)\right] d\tau$$

eq. 2-3

where: L = level variable [units]
L_0 = initial value of level [units]
IR = function defining the inflow to L being a function of τ [units/time]
OR = function defining the outflow from L being a function of τ [units/time]
τ = integral variable, in this case a period of time

Flow variables respectively rates determine all inflows and outflows of level variables. Values of level variables, auxiliary variables and constants are controlling the flows from, to and between level variables in this equation. Flow variables can be described with the following equation:

$$R(t) = f(levels, const, aux) = f(L, c, a)$$

eq. 2-4

where: R = flow variable respectively rate [units/time]
L = level variable [units]
c = constant variable [units]
a = auxiliary variable [units]

Parameters respectively constant variables remain constant during the whole simulation period with one exemption: lookup variables allow the predefined variation of parameters over time. The time or any other system variable can act as input for lookup variables. For each input value the modeller determines an output within the lookup variable. The system environment contains all exogenous influences. According to the definition exogenous variables can impact the systems behaviour but are not influenced by the system themselves. Auxiliary variables calculate all impacts on variables that take place at the same point of time.

System Dynamics models can require decision rules. If the modeller wants to simulate feedbacks that can change over time he has to determine decision rules. Then, changes of flow variables follow these rules. The thermostat example from the previous chapter can demonstrate the requirements on decision rules. At first the modeller has to define a target value for a variable in the system. The system state provides the necessary information to compute the difference between desired and actual state. Based on this difference the modeller integrates specific changes or resulting actions that can feed back into the original information.

Mathematical simulation declares and solves all equations of a System Dynamics model. For this purpose Forrester developed special System Dynamics software called DYNAMO compiler. Since then several user-friendly software packages were following. The most common are iThink®, STELLA®, Powersim or Vensim®. They simplify the development of System Dynamics models and allow the modeller to concentrate on the core modelling process which is to implement feedback structures. All software packages provide useful tools like graphical representation of the model, error checks and the solving of the difference equations.

Originally, System Dynamics models consist of non-linear differential equations. Regarding the complexity of models simulating social systems the computational requirements set by differential equations can hardly be realised. The substitution of differential equations by difference equations and their sequential solution through numerical integration allowed for simulating time paths for the variables of the system.

All System Dynamics tools available offer at least two mechanisms of numerical integration. The simplest, in terms of accuracy for exact approximations of certain models, sometimes insufficient mechanism is the integration of *Euler*. John Sterman from MIT considers the Euler integration as "*almost always fine in models of social and human systems where there are large errors in parameters, initial conditions, historical data"* (STERMAN 2000, p.911). The quality of the simulation via Euler integration can be improved by decreasing the integration time step *dt*. If the choice of small time steps is not possible and accuracy is essential for a reliable simulation of model behaviour, the common System Dynamics software provides the alternative to switch to *Runge-Kutta-4* approximation. In contrast to Euler integration the Runge-Kutta-4 method computes in each time step four subsequent equations. The four equations are computed in a sequence and use the result of the previous equation as input. The first three calculation steps compute with a halved time step *dt* and the final step uses the full time step *dt*.

3 Ex-Ante State of ASTRA

This section describes the former state of the ASTRA model before new models were integrated and existing models were adjusted for this thesis. It highlights the origin and basic modelling concept of the ASTRA model and provides an overview of the whole modelling framework. The overview is followed by a more detailed description of the single modules, the most important outputs and inputs and their interaction. A set of important feedback loops of the complete model is presented before the section concludes with a depiction of the sectoral and spatial classification structures of ASTRA.

3.1 Concept of ASTRA

Transport plays an essential role for the functioning and growth of economy. This hypothesis was confirmed by many economists and transport scientists and was focussed in documents like the White Paper of the European Commission "European transport policy 2010: Time to decide" (CEC 2001). Globalisation in economy keeps on proceeding and networks keep on opening which implicates growing transport activities. Apart from the economic benefits of increased transport flows, the burden caused by growing transport activities has to be kept in mind. Therefore a major challenge for policy makers in the transport sector is to achieve economic growth in an environment-friendly way or in other words to support sustainable development with policy actions.

Regarding the current tools applied for European policy assessment, static Cost-Benefit Analysis (CBA) in combination with Strategical Environmental Assessment (SEA) is still dominating even if its deficits are well-known. The idea of an integrative approach which is necessary for analysing long-term impacts of transport, environment and socio-economic systems and its reciprocity is missing in this method. The original vision of the ASTRA modellers was to develop a tool enabling strategic sustainability analysis on European level. The question on how to integrate socio-economic, transport and environmental assessment of European transport policy, technological and environmental scenarios was the major challenge in this stage.

Based on the requirements of such an integrated socio-economic, transport and environmental model System Dynamics was chosen as best methodology for developing this model. The System Dynamics standard software Vensim® provided the modelling platform for the development of the ASTRA model. Starting point for this development was a research project of the 4th framework programme of the European Commission called ASTRA (IWW ET AL 2000). The project was carried out by the Institute for Economic Policy Research (IWW), Karlsruhe, Trasporti e Territorio (TRT), Milan, Marcial Echenique & Partners (ME&P), Cambridge, and Centre for Economics and Business Research (CEBR), London, and started in the year 1998.

ASTRA, the name of the model, was derived from the abbreviation of the project “ASsessment of TRAnsport strategies” which represented the main objective of the model development. The modellers of the basic ASTRA version geared on the structure of three existing models: the European transport model SCENES (2000) developed by Marcial Echenique & Partners (ME&P), the macroeconomic System Dynamics model ESCOT

(SCHADE/ROTHENGATTER/SCHADE 2002) established by the Institute for Economic Policy Research (IWW) and a set of environmental models that have been developed for purposes of Strategic Environmental Assessment (SEA) of the German federal cross-modal transport infrastructure plan BVWP (GÜHNEMANN 2000). The modellers analysed and selected the major feedback loops implemented in these models and adopted them in ASTRA which was a challenging task as only the ESCOT model was implemented in System Dynamics. Hence, large parts of the final model differ significantly from the originating models as only the core feedback structures maintained. Besides the possibility of simulating feedback structures, the capability of implementing elements of various modelling approaches argued for the application of System Dynamics methodology. Different techniques from other modelling approaches were incorporated in ASTRA. For example, ASTRA contains attributes of econometric models as, partially, the functional relationship between variables were empirically estimated. Furthermore, input-output analysis was applied to picture the interweavement of economic sectors. Finally, also equilibrium approaches were used in a modified way as they are commonly used in transport modelling. At first glance, this seems to be unusual as from the neo-classical view System Dynamics can be assigned to disequilibrium approaches but after a closer look the modifications adapt the original approach to the sense of System Dynamics. Another important feature of System Dynamics is the capability to support the analysis and visualisation of systems. Therefore, System Dynamics could improve the decision-making process because decision-makers are supported in understanding the system behaviour and the outcome of the model.

Since the ASTRA project the model has been further developed, extended and improved within numerous research projects mainly on behalf of the European Commission. The TIPMAC (SCHADE/KRAIL et al. 2004) project provided the basis for the so far most comprehensive description of ASTRA in the dissertation thesis of SCHADE (2005). Other important milestones in the ASTRA model development could be achieved in projects like LOTSE (KRAIL/SCHADE 2004), IASON (SCHADE et al. 2004), TRIAS (KRAIL et al. 2007), HOP (SCHADE et al. 2007), PROGRESS, iTREN and KlimaInvest2020. During the LOTSE project the first contribution to this thesis has been carried out. Socio-economic, transport and environment systems of the 12 European countries acceding the European Union in 2004[4] and 2007[5] plus Norway and Switzerland were added to the already established EU15 countries.

3.2 Overview of ASTRA

In the following sections the state of the former ASTRA model without integration and revision of models for this thesis is being presented. As the modelling work for this thesis has been carried out continuously during the last five years, the description of the model state does not represent the state of ASTRA directly before the final integration of the last modules in the year 2008. The first model parts presented in this thesis were already integrated in the year 2004 while the major model development and revision was integrated in the year 2008. Nevertheless, this chapter provides an overview of the underlying ASTRA model, the single modules of ASTRA and their interaction.

[4] EU Accession Countries in 2004: Cyprus, Czech Repulic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovenia and Slovakia

[5] EU Accession Countries in 2007: Bulgaria and Romania

Originally, the base ASTRA model consisted of nine modules that were all implemented for the simulation of the complete model within one Vensim® system dynamics software file. For many years now, the ASTRA model has been developed not only by the Institute of Economic Policy Research (IWW) at the University Karlsruhe (TH) but also by the colleagues from Fraunhofer-ISI in Karlsruhe and Trasporti e Territorio (TRT) in Milan, a new solution for efficient distributed model development had to be found. In the context of the TRIAS project the complete ASTRA model has been split into overall 37 sub-modules in order to avoid labour-intensive integration of model revisions caused by parallel work on the complete ASTRA model. Additionally, the error rate caused by update-processes during parallel model development could be reduced to a minimum. From that time on, each of the 37 sub-modules can be refined or extended by each of the three institutions and finally be merged to a complete integrated ASTRA model. Revised model files for all sub-modules and exogenous data files can be reallocated via a repository such that all partners can access the most recent ASTRA model.

This thesis is based on the ASTRA model version that simulated the socio-economic, transport and environmental development of the EU27 member states plus Norway and Switzerland[6] between 1990 and 2050 with an integration time step of a quarter year. One scenario simulation between 1990 and 2050 with two-year-saving intervals of the selected result indicators generates more than 900 Mega-Byte of output data. Regarding the size of the model that incorporated about 29 million objects, the enormous storage size is not astonishing. In Vensim® each variable which is equal to equations is defined as an object. The fact that more than one million objects were level variables demonstrates the integrated dynamics in ASTRA. Two major types of level variables could be distinguished: delay variables and accumulating variables of which the former stand for the greater share of level variables in the model. Variables of the basic ASTRA model were grouped into the following nine modules:

- Population module (POP),
- Macro-economic module (MAC),
- Foreign trade module (FOT),
- Regional economic module (REM),
- Transport module (TRA),
- Infrastructure module (INF),
- Vehicle fleet module (VFT),
- Environment module (ENV) and
- Welfare measurement module (WEM).

An overview of the nine modules and their main interfaces is presented in Figure 3-1. The aggregate level of the figure provides the only exhaustive presentation of the basic ASTRA model. Going to one further level of detail with the description would already be outside what could be presented within one figure or one comprehensive set of equations. To cope with this

[6] For simplification reasons the abbreviation EU27+2 is used for the EU27 countries plus Norway and Switzerland.

difficulty, the following sub-sections are zooming top-down into the details of the model necessarily having some overlap in the descriptions from the upper levels to the more detailed levels to pick-up the thread at each level of description again.

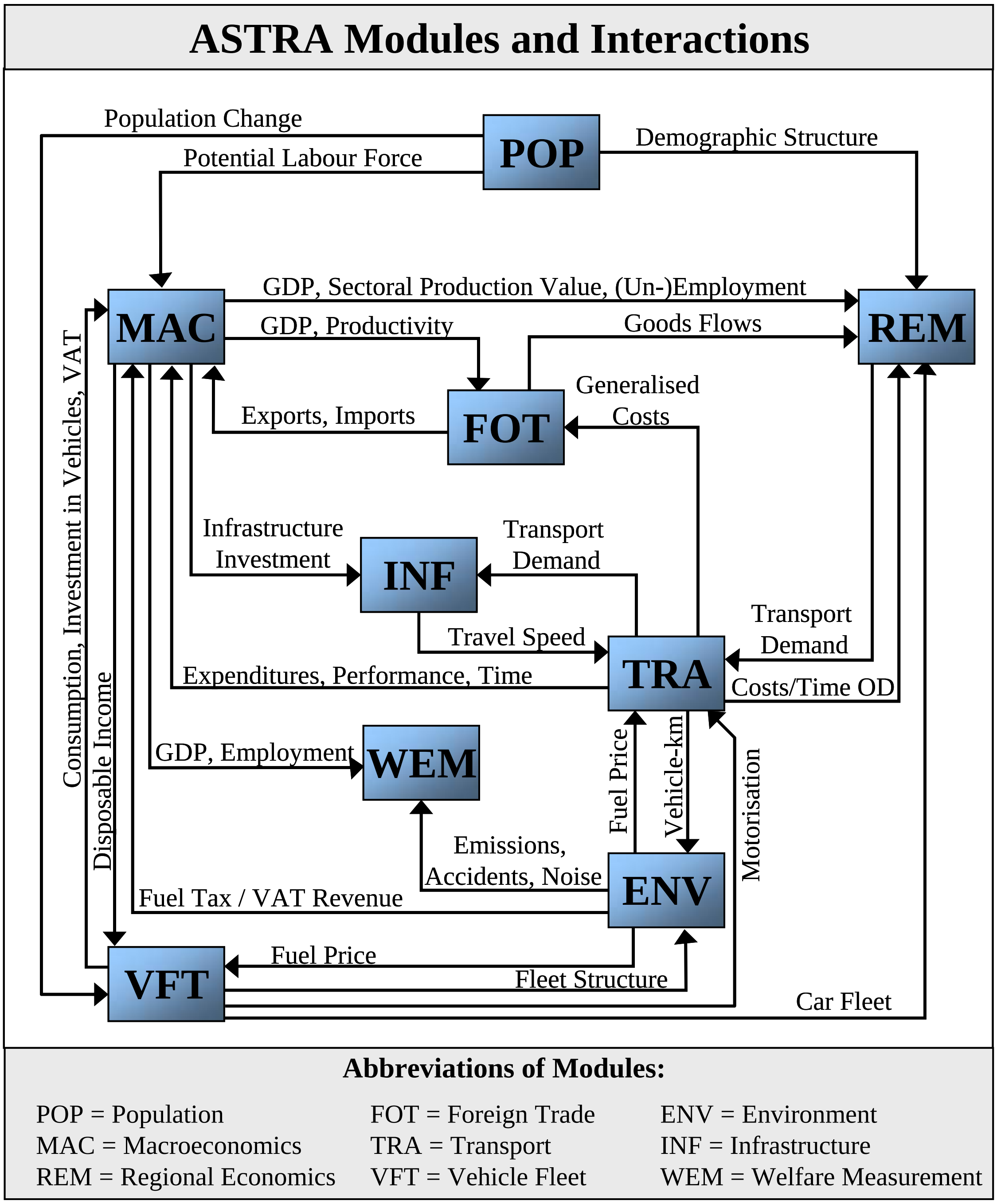

Figure 3-1: ASTRA Modules, Main Outputs and their Interactions

3.2.1 Population Module

The objective of the Population module (POP) is to enable a differentiation of population groups that are relevant for analysing transport and economic patterns. Therefore, the POP module simulates the demographic development for the EU27+2 countries with one-year-age-cohorts, such that the population of a country is subdivided into one-year-person-groups starting with babies and ending with persons older than 80 years. Mathematically, the population model simulates the population even in quarter-year steps such that there are actually 320 cohorts. In principle, the core of the POP module can be described by *eq. 3-1* which computes the age structure of the population per country. Persons enter the level variable either by birth or by immigration and leave the variable by death and emigration. Additionally, persons leave their age cohort every time step and join the following age cohort.

$$POP_{i,c=0}(t) = (1 - IM_i) * SW_i * FR_i * \sum_{c=0} [POP_{i,c}(t-dt)] - P_{i,c}(t-dt)$$
$$POP_{i,c\in[2,16]\vee c\in[45,80]}(t) = (1 - DR_{i,c-1}) * POP_{i,c-1}(t-dt) - POP_{i,c}(t-dt)$$
$$POP_{i,c\in[17,44]}(t) = (1 - DR_{i,c-1}) * POP_{i,c-1}(t-dt) + MB_{i,c}(t) - POP_{i,c}(t-dt)$$
$$POP_{i,c=80}(t) = (1 - DR_{i,c-1}) * POP_{i,c-1}(t-dt) + (1 - DR_{i,c}) * POP_{i,c}(t-dt) - DR_{i,c} * POP_{i,c}(t-dt)$$

eq. 3-1

where:
POP = number of persons per country *i* and age cohort *c*
IM = infant mortality at birth
SW = share of woman in child bearing age
FR = fertility rate
BR = birth rate
DR = death rate of age cohort *c*
MB = migration balance into age cohort *c*
dt = time differential to previous point of time for difference equations
i = index for EU27+2 countries
c = index for cohorts 0 to 80

The model with the population level in its centre depends on country-specific fertility rates, death rates and migration balances. According to EUROSTAT (2008a) birth statistics the countries are differentiated into countries with early bearing women (age between 15 and 40 years), medium bearing women (age between 20 and 45) and old bearing women (age between 24 and 49). Trends observed in the past years, such as growing life expectation or decreasing infant mortality rates, are integrated in the simulation of population. Based on the age structure modelled by the one-year-age-cohorts, important demographic information is provided to several other modules. Therefore, different age groups that are relevant as input into other ASTRA modules are aggregated. The number of persons in the working age which is called labour force in the following is used as input in the Macroeconomic (MAC) module. The number of persons in defined age classes serves as input for the simulation of age specific mobility behaviour in the Regional Economics (REM) module. The development of adult population provides a valuable input for the Vehicle Fleet (VFT) module. The POP module is calibrated to fit EUROSTAT (2008a) population statistics and baseline projections until 2050. For this reason, parameters like country-specific death rates, future fertility rates, the age structure of immigrants and emigrants and a factor simulating the future life expectancy and health improvements reducing infant mortality rates are adjusted.

3.2.2 Macroeconomic Module

The main objective of the Macroeconomic (MAC) module is to simulate the national economic framework estimating important indicators that are essential for a comprehensive modelling of all other modules. Regarding the original vision of the ASTRA model development – the assessment of transport strategies – the macroeconomic module has to simulate the impacts of money flows and compensation mechanisms which are induced by transport policies. These impacts can be initiated by new transport infrastructure investments, additional road charging expenditures, energy price developments, changes of taxation, etc.

Originally, the MAC module was developed under consideration of several economic theories. Thus, it cannot be categorised explicitly into only one economic category of models for instance a neo-classic model. The MAC contains neo-classical elements like Cobb-Douglas production functions as well as Keynesian elements, e.g. the dependency of investments on consumption and other influences like exports. Moreover, also characteristics of Endogenous Growth Theory can be found within it, e.g. the dependency potential output on technical progress in terms of total factor productivity. Furthermore, the MAC module also shows attributes of an econometric model. The main output indicator of the MAC module is the gross domestic product (GDP) per country. In contrast to computable general equilibrium (CGE) models, the GDP is driven by the demand and supply side of an economy. The following equation demonstrates the implemented dependency of both sides.

$$GDP_i(t) = \begin{cases} wFDa_i * FD_i(t) + (1 - wFDa_i) * PO_i(t) \rightarrow FD_i(t) > PO_i(t) \\ wFDb_i * FD_i(t) + (1 - wFDb_i) * PO_i(t) \rightarrow FD_i(t) \leq PO_i(t) \end{cases} \quad \textbf{eq. 3-2}$$

where: *GDP* = gross domestic product
FD = final demand
PO = potential output
wFDa = weight of final demand if FD>PO
wFDb = weight of final demand if FD<=PO
i = index for EU27+2 countries

As opposed to CGE models, the ASTRA MAC module does not simulate the development of prices. Hence, all monetary values of the MAC and all other modules are based on the real term concept and express their values in constant prices of the year 1995.

Regarding the structure of the ASTRA MAC module, the variables can be assigned to six major sections according to their functionality:

- The sectoral interchange model reflects the interweavements between 25 economic sectors of the national economies.
- The demand-side model depicts private household consumption, government consumption, investments and exports-imports and, hence, all four components of final demand.
- The supply-side model simulates influences of the production factors labour, capital stock, natural resources and technical progress on potential output of an economy.
- The employment model computes the development of EU27+2 labour markets in terms of full-time, part-time and full-time-equivalent employment based on labour productivity and gross value-added as output from sectoral interchange model.
- The government model accounts all revenues, like all forms of taxes, contributions of citizens and revenues from transport charges, and expenditures, e.g. transfers, government consumption and interest payments, of the governments and represents the government behaviour.
- The micro-macro bridges link all micro- and meso-level models, e.g. the Transport module (TRA) or the Vehicle Fleet module (VFT), with the MAC module and vice-versa.

3.2.2.1 Sectoral Interchange Model

The main objective of the sectoral interchange model is to simulate the indirect effects of developments within the modelled 25 economic sectors. The chosen differentiation into 25 economic sectors which is used in the consumption, investment and employment model as well is described in detail in paragraph 3.2.10.1. Shifts between sectors of consumption and investment impact the sectoral interweavement such that the basic input-output tables are not being kept constant over time. Changes in sectoral final use composed out of sectoral household and government consumption, sectoral investments and sector exports influence the structure of the input-output tables as well as transport and energy price changes. This impact is implemented by updating the inverse input coefficients, the so-called *Leontief Inverse*, (LEONTIEF 1966) under the assumption that a constant relationship between value-added and total use exists. This process is repeated after each change of the intermediates matrix. Then, the re-calculation of the matrix of intermediates is based on the matrix of updated inverse input coefficients. This approach is derived from the ESCOT model (SCHADE/ROTHENGATTER/SCHADE 2002).

The sectoral interchange model is based on harmonised national input-output tables taken from EUROSTAT (2008b). The data of the first quadrant of the national input-output tables is taken and adjusted to compute initial 1990 values due to the fact that the basic tables stem from the years 1995 to 1997. The major outputs of the sectoral interchange model are gross-value added and national production value per sector. Future trends in almost all industrialised EU27+2 countries, such as growing gross-value-added gained in service sectors and simultaneous decreasing importance of manufacturing sectors, is supported by the sectoral interchange model.

3.2.2.2 Demand-Side Model

The demand-side model of the ASTRA MAC module is further differentiated into sub-models simulating national and disposable income, taxes, sectoral private household consumption and sectoral investments. The main output of the demand-side model is the final demand per sector (eq. 3-3) composed out of private household consumption and investments per sector computed within the demand-side model, sectoral government consumption provided by the government model and sectoral exports and imports from the Foreign Trade module (FOT).

The monetary level of total consumption is driven by disposable income of private households and savings ratio. In the ASTRA MAC module, the disposable income is derived from GDP according to national accounting framework. In the first step, gross national income is calculated by adding primary income of citizens living in other countries to GDP. Then depreciation, subsidies and indirect taxes are subtracted and lead to the level of national income. Finally, transfers to households are added while direct taxes, social contributions and company profits are subtracted. The resulting total disposable income of private households is reduced by the savings which are determined in the calibration process of the consumption model. The consumption model can be separated into two parts: the consumption of sectors directly influenced by transport and other sectoral consumption. Transport (TRA), Vehicle Fleet (VFT) and Environment (ENV) module provide inputs like fuel consumption, passenger-kilometres per mode and purchase of cars per car category that are transformed via micro-macro bridges into monetary consumption of the transport sectors. Consumption of products assigned to all other sectors is induced by statistical share of consumption per sector.

$$FD_{i,s}(t) = C_{i,s}(t) + I_{i,s}(t) + EX_{i,s}(t) - IM_{i,s}(t) + GC_{i,s}(t) \qquad \textbf{eq. 3-3}$$

where: *FD* = final demand
C = consumption of households
I = investments
GC = government consumption
EX = exports
IM = imports
s = index for 25 economic sectors
i = index for EU27+2 countries

The structure of the investment model is similar to the consumption model. The TRA module, VFT module and Infrastructure (INF) module provide necessary information for the investments of transport sectors. Investments in business cars, coaches, trucks, trains, ships and planes are covered as well as required transport network investments or investments in transport facilities. Implemented Keynesian effects and other impacts lead to changes in investment level of non-transport-related sectors. Hence, the growth of consumption and exports per sector influence the growth of investment goods sectors. Furthermore, increasing government debts resulting in increasing interest rates dampening private investments are considered as well as the impacts of the ratio between final demand and potential output. If final demand is lower than potential output, the investment elasticity to consumption and exports is supposed to decrease and vice-versa.

3.2.2.3 Supply-Side Model

The major output of the supply side model is the total potential output of an economy based on the changes of production factors. The following neo-classical production function of Cobb-Douglas type estimates the potential output based on gross capital stock, labour supply, natural resources and technical progress referred to as total factor productivity (TFP).

$$PO_i(t) = bPO_i + cPO_i * TFP_i(t-dt) * (L_i(t-dt))^{\alpha} * (CS_i(t-dt))^{\beta} * (NR_i(t-dt))^{\gamma} \qquad \textbf{eq. 3-4}$$

where: *PO* = potential output
bPO = calibrated parameter for base level variable
cPO = calibrated parameter for trend factor
TFP = total factor productivity
L = labour supply in working hours
CS = capital stock
NR = natural resources (exogenous)
α = calibrated production elasticity labour supply
β = calibrated production elasticity capital
γ = production elasticity natural resources
i = index for EU27+2countries

Gross capital is calculated endogenously as well as labour supply and total factor productivity. New investments provided by the investment model and depreciations calibrated via the depreciation period are the main inputs required for the estimation of gross capital stock. Labour supply in terms of total hours worked is derived from the employment numbers simulated in the employment model. As ASTRA does not model the exploiting and regeneration of national resources, this production factor enters the production function as an exogenous parameter. Finally, the ASTRA model depicts the development of technical progress. Main drivers of technical progress are labour productivity trends, development in sectoral investments and improvements in freight transport times. The influence of changes of sectoral investments on technical progress is weighted per sector, as some sectors, such as the electronics sector are supposed to be more important drivers of technical progress than others. The TRA module provides freight transport times per origin-destination that are aggregated via micro-macro bridges.

3.2.2.4 Employment Model

The employment model simulates the development of national labour markets, estimates sectoral employment trends, distinguishes between full-time and part-time employment and computes unemployment. It provides valuable information for several other modules and models of the MAC module. For example, the data of total hours worked is used as input in the production function, employment and unemployment numbers are needed to calculate social contributions, direct taxes and benefits for unemployed as revenues and expenditures in the government model and at the same time employment is considered as an important factor in the passenger trip generation modelled in the Regional Economics (REM) module. Based on gross value-added per sector, the main output indicator from the sectoral interchange model and labour productivity per sector the employment model computes full-time-equivalent employment per sector (eq. 3-5).

$$FTE_{i,s}(t) = \frac{GVA_{i,s}(t)}{LP_{i,s}(t)} \qquad \textbf{eq. 3-5}$$

where: FTE = full-time-equivalent employment
GVA = gross-value added
LP = labour productivity
s = index for 25 economic sectors
i = index for EU27+2 countries

Labour productivity per sector is derived from statistical numbers for full-time-equivalent employment and gross value-added per sector for the period from 1990 to 2005. For future development, a trend for labour productivity has been estimated which is strongly influenced by the development of unemployment. The model considers reactions of the economy on low unemployment rates that improve labour productivities per person. The integration and continuation of statistical trends for part-time and full-time employed per sector allow the estimation of total full-time and part-time employment per sector. Activity rates that are calibrated in the POP module provide the necessary information to determine unemployment rates per country.

3.2.2.5 Government Model

The main objective of the government model is to account all revenues and all expenditures of a national state in order to provide significant information to other models. All kinds of taxes, like value-added, direct, indirect, import, vehicle and other taxes, social contributions from employees pricing revenues from state-owned transport infrastructure are opposed to expenditures, like social benefits to retired, unemployed, children and others, subsidies, government investments and consumption. If revenues are higher than expenditures government debts are supposed to be repaid whereas the other condition results in increasing debts.

3.2.2.6 Micro-Macro Bridges

Micro-macro bridges are relevant for an integrated macroeconomic, transport and environment model as they connect micro- and meso-level models for instance the TRA, the VFT or the ENV module with the MAC or Foreign Trade (FOT) module. Their main function is to differentiate information in one direction and aggregate information into the other direction. Examples for micro-macro bridges are consumption of transport services like trips with busses, railways or planes that are aggregated by average costs per passenger-kilometre into total consumption per sector and country or the consideration of average transport costs in the sectoral interchange model derived from detailed transport costs per mode and origin-destination.

3.2.3 Foreign Trade Module

In the period between 1990 and 2005, foreign trade was one of the major drivers of economic growth in most EU27+2 countries. Annual export growth rates are often significantly higher than growth rates of all other important macroeconomic indicators. Improvements in transport systems like efficient logistics or faster connections led to removing trade barriers. Expert expectations confirm that future economic growth will be strongly influenced by foreign trade even if energy prices are continuously increasing which would have a negative impact on trade flows.

The Foreign Trade (FOT) module can be differentiated into two parts. The first part represents foreign trade between the EU27+2 countries, the so-called INTRA-EU trade model, while the second part simulates foreign trade between the EU27+2 countries and countries in the rest-of-the world, the EU-RoW trade model. Countries in the rest-of-the-world (RoW) are assigned to nine regions: Oceania, China, East Asia, India, Japan, Latin America, North America, Turkey and Rest-of-the-World. The structure of the two models is similar as both models are differentiated into bilateral trade flows by country pair for each of the 25 economic sectors. Regarding the implemented dynamics, the INTRA-EU trade model contains more endogenous drivers than the EU-RoW trade model.

Three endogenous and one exogenous factor determine the development of trade between EU27+2 countries. Measured historical and estimated future world GDP growth is supposed to be an important driver of foreign trade. A look at historical time series of exports and world GDP growth demonstrates a strong correlation. Hence, world GDP growth is considered to be a valuable exogenous input for the INTRA-EU trade model. GDP growth rate of the importing country is the first endogenous influence on trade flows. As consumption and production processes of a country are strongly affecting GDP, this indicator has been chosen as a driver of foreign trade. Competitive advantages compared to trade partners are simulated by an influencing factor representing relative changes of sectoral labour productivities between importing and exporting country. Averaged generalised costs of passenger and freight transport between the trade partners are aggregated from the detailed transport costs and times and reflect the accessibility of a certain trade partner.

In contrast to the INTRA-EU trade model the EU-RoW trade model can not consider transport costs and times as an impact as the ASTRA TRA module covers only transport activities within EU27+2 countries. Hence, this model is mainly driven by relative productivity between the European countries and the RoW regions. Productivity changes together with GDP growth of the importing RoW-country and world GDP growth drive the export-import relationships between the countries.

The resulting sectoral export-import flows of the both trade models are fed back into the MAC module as part of final demand and national final use respectively. Furthermore, the INTRA-EU trade model provides the input for international freight generation and distribution within the REM module.

3.2.4 Regional Economics Module

As the ASTRA model focuses on the assessment of transport, technology and environment policies, an accurate simulation of passenger and freight transport can be considered as important as the realistic presentation of socio-economic systems of the EU27+2 countries. After years of development and practical application, one modelling method stands out: the classical four-stage transport modelling approach (ORTÚZAR/WILLUMSEN 1990, p.23). The first time the so-called four-stage model was applied in several metropolitan case studies like the Detroit Area Traffic Study (DATS 1955), the Chicago Area Transportation Study (BLACK 1990) or the study for the city of London (BATES 2000). The classical four-stage model consists of four sub-models in a sequence: trip generation, distribution, modal split and assignment. The stages of trip generation and distribution, both for passenger and freight transport, are implemented in the ASTRA Regional Economics (REM) module. The following chapters describe the structure of both sub-models for passenger and freight as well as their major outputs. As these stages are managed in quite different ways for passengers and freight, they are examined separately in the following.

3.2.4.1 Passenger Trip Generation

Originally, the passenger trip generation of state-of-the-art four-stage models can be differentiated into two parts: trip production and trip attraction. Trip production comprises the computation of the total number of trips per year for three trip purposes originating in each functional zone in EU27+2 countries, while trip attraction simulates the number of trips per year and trip purpose that have their destination in a certain functional zone. In brief, each of the EU27+2 countries is subdivided into one, two or four functional zones according to settlement patterns and level of GDP per capita. A detailed description of the spatial differentiation into function zones follows in chapter 3.2.10.2. The resulting trip vectors provide the required input for the distribution stage that is performed by a gravity function. Originated and attracted trips represent the attracting masses in this gravity function. The number of trips from origin zone to destination zone per trip purpose without differentiation into transport modes is the output of the distribution stage.

As opposed to the described distribution approach, an alternative approach has been chosen for the ASTRA REM module. The original approach using a gravity function in the distribution stage could not be implemented because of the necessary adjustment processes. Balancing factors have to be computed in a FURNESS (1965) iteration approach in order to control the multiplication of originating and attracted trips. Four-stage transport models are usually applied in static approaches, while ASTRA calculates results in every single integration time step between 1990 and 2050. Therefore, the Furness iteration process adjusting the trip matrix for each trip purpose at each time step would prerequisite that computational resources are not used to full capacity. In fact, the ASTRA model can only be simulated on personal computers or servers with high-grade equipment. Based on this finding, the basic ASTRA model contains a distribution approach that requires only the assessment of originating trips in the trip generation stage.

In ASTRA, the trip generation is performed by multiplication of average yearly trip rates per person with the number of persons that live in a functional zone. The following equation describes the computation of originating trips:

$$OT_{i,z,tp,ps,ca}(t) = POP_{i,z,ps,ca}(t) * TR_{i,tp,ps,ca}(t) \quad \textbf{eq. 3-6}$$

where:
- OT = number of trips per country i, functional zone z, trip purpose tp, population segment ps and car availability ca
- POP = persons per country i, functional zone z, population segment ps and car availability ca
- TR = trip rate per country i, trip purpose tp, population segment ps and car availability ca
- i = index for EU27+2 countries
- z = index for functional zone
- tp = index for three trip purposes
- ps = index for population segment
- ca = index for car availability status

Trip rates reflect the specific propensity of persons with certain characteristics and, thus, are differentiated into representative combinations of person attributes. Basic ASTRA trip rates were derived from the SCENES (ME&P 2000) model for all EU15 countries. They were differentiated into three trip purposes (business, private and tourism), four population segments (children younger than 16 years, employed persons between 16 and 64 years, unemployed persons between 16 and 64 years and retired persons older than 64 years) and three car-availability categories (full access to car, shared car and no car available). According to the predefined combination of attributes in SCENES trip rates, persons are assigned to the different attribute combinations. Demographic structures are provided by the POP module, employment status by the MAC module and car-availability by the Vehicle Fleet (VFT) module.

Most Western European countries and members of EU15 frequently performed mobility or travel surveys among the population helping to identify mobility patterns of specific population clusters, for example the German Mobility Panel and the Dutch National Travel Survey or the British National Travel Survey. Analysing and comparing these mobility surveys led to the insight that mobility patterns and average numbers of trips per person in these countries resemble one another. Country-specific GDP per capita from EUROSTAT (2008b) show that the values of the year 2000 are also similar and in a range between 25,000 and 26,500 Euro per inhabitant. In contrast to the various information on trip rates provided by these and many other Western European mobility surveys, no surveys were available for the New Member States of the EU27. This lack of information and data required the development of an appropriate methodology to estimate the passenger trip rates in the New Member States. Unfortunately, no available transport database releases total numbers of passenger trips for these countries. Only the passenger transport performance measured in passenger-km can be found in databases like the "EU Energy and Transport in Figures" pocketbook published by the European Commission each year. This country-specific transport performance indicator could serve as basis for the estimation of trip rates. In practise a transfer from passenger-km into passenger trips would require an estimation of average length of trips differing from country to country depending on country specific settlement patterns, the location of workplaces and other indicators. Therefore an alternative methodology has been chosen to estimate the passenger trip rates in the New Member States.

According to the differentiation of trip rates in EU15 countries, the country specific trips per person and day are distinguished between the three trip purposes business, private and tourism. The British National Travel Survey provides reference values per person and day for all three purposes. In 2000, a person in the UK made on average about 2.5 business trips per day, 1.85 private trips per day and 25 holiday trips (trips of more than 2 days) per year. Furthermore, the GDP per capita for the initial year 1990 has been taken from EUROSTAT (2008b). The computation requires the assumption of a minimum number of trips per person and trip purpose per day. This assumption has been performed by determining a minimum number of average trips per person and year of about 800 trips compared to 1021 in the UK. The assumption of business trips being more essential than private or holiday trips and people with lower incomes have to save money by reducing the number of holiday and private trips resulted in the following minimum number of trips per person: 2.3 business trips, 1.5 private trips and 4 holiday trips.

In comparison with the trip rates for EU15, the resulting trip rates for the Eastern European New Member States of EU27 are only disaggregated into three trip purposes and do not consider employment or car-availability. The EU15 passenger trip generation model was originally based on trip rates per age segment, employment status, car-availability and trip purpose taken from SCENES. As these trip rates did not distinguish between different mobility patterns from country to country a special calibration was implemented in ASTRA. The country specific differences were taken into account by calibrating the trip rates to fit the total numbers of trips per purpose and functional zone in a country. For the estimation of Eastern European trip rates the same approach was applied.

Hence, in the approach the total number of trips per country in a year was computed out of the number of average trips per person and trip purposes by applying employment and population numbers for the initial year 1990 taken from EUROSTAT (2008a). The total number of business trips was calculated by assuming an average of 260 working days per year and multiplying them with the employment numbers and trip rates. For the computation of yearly private and holiday trips the whole population was considered. Splitting the trips per country and trip purpose into the functional zones by taking into account the share of population living in the zone, enabled the recalculation of country-specific trip rates originally taken from SCENES.

3.2.4.2 Freight Demand Generation

Generation of freight demand is mainly driven by the production of physical goods. As the result of industrial activity is generally consumed far from the production location, the larger the amount of products the higher the freight traffic.

Hence, the starting input is represented by the value of production of physical goods provided for each sector, by MAC and FOT modules. National and international transport are treated differently since the former depends on domestic output per sector, while the latter depends on country-wise export flows that already incorporate a distribution. In both cases the monetary aggregates are put into volumes of generated freight demand by dividing them by the average unitary values of production in each sector:

$$V_{i,s}(t) = \frac{O_{i,s}(t)}{VVR_s(t)} \qquad \textbf{eq. 3-7}$$

where: *V* = Volume of goods generated by sector *s* in country *i*
O = Value of production of sector *s* in country *i*
VVR = value-to-volume ratio of sector *s*
i = index for EU27+2 countries
s = index for 25 economic sectors

The unitary values of production, expressed in EURO/ton were estimated from available statistics. The unitary values are assumed to decrease slightly in the future i.e. the same monetary flow will generate less tons of transport due to an expected trend towards higher value goods. As for passengers where three trip purposes are considered, three different handling categories are defined: bulk (e.g. oil, sand, cereals), general cargo (e.g. machinery, building materials) and unitised (e.g. containers, swap bodies).

3.2.4.3 Passenger and Freight Distribution

The main objective of passenger trip distribution consists in the assignment of generated trips among all possible destinations. As above-mentioned, the passenger trip distribution among all available destinations is estimated by a Logit algorithm:

$$p_{od} = \frac{e^{-\lambda * u_{od}}}{\sum_d e^{-\lambda * u_{od}}} \qquad \textbf{eq. 3-8}$$

where: λ= spread parameter
p = probability that demand generated in origin *o* choose destination *d*
u = disutility of the trip from origin *o* to destination *d*

The implemented utility function consists of a term that accounts averaged generalised times per trip from origin to destination per trip purpose with a specific disutility or resistance for this origin-destination link. Generalised times per origin-destination link per trip purpose per passenger mode are provided by the Transport (TRA) module. Weighted by the simulated traffic volume per passenger mode on the specific origin-destination links, average generalised times were calculated. For freight, average generalised cost is used instead. Generalised time is calculated as travel time plus the equivalent, in time terms, of the costs of the trip. The translation of cost into time is based on value-of-time differentiated by trip purpose and by handling category. The computation of average generalised cost for freight requires similar elements but the translation concerns time into monetary units. Value of time represents the monetary value of a unit of time. It strongly depends on the trip purpose respectively goods category.

As in real transport systems, passenger and freight transport modes are not available for all distances, trips and freight demand are assigned to predefined distance bands. Five passengers distance bands are implemented: local (LC, distances below 3.2 km), very short (VS, distances => 3.2 and < 8 km), short (ST, distances => 8 and < 40 km), medium (MD, distances => 40 and 160 km) and long (LG, distances > 160 km) distances. Freight transport is differentiated into four distance bands: short (LOC, distances < 50 km), medium-short (REG, distances => 50 and < 150 km), medium-long (MED, distances => 150 and 700 km) and long (LGD, distances > 700 km) distances. Distance bands were assigned to each possible origin-destination pair according to the average distance of road freight modes and passenger car mode.

3.2.5 Transport Module

The ASTRA Transport (TRA) module carries out the third stage of the classical four-stage transport model, the freight and passenger modal split. The implemented passenger modal split model simulates the probability of a person's decision to use one out of all available transport modes for a trip from origin to destination zone for a certain trip purpose. The modal split is performed with a discrete choice modelling approach that is based on random utility theory (DOMENICH/MCFADDEN 1975). Basic assumptions are that persons act rationally and possess perfect information, a set of alternative modes exists and each alternative associates a net utility. Among the existing different specifications of discrete choice models, the selected modal split modelling approach can be assigned to the group of multinomial probit models (ORTÚZAR/WILLUMSEN 1990, pp.235). The following equation illustrates the calculation of the mode-specific probability for passenger transport. The only difference between passenger and freight transport logit equations is that freight modal split is estimated for three goods categories instead of trip purposes.

$$P_{o,d,tp,pm}(t) = \frac{e^{-\eta * U_{o,d,tp,pm}(t)}}{\sum_{pm} e^{-\eta * U_{o,d,tp,pm}(t)}} \qquad \textbf{eq. 3-9}$$

where:
- η= spread parameter
- P = probability of using mode *pm* for the trip from origin *o* to destination *d*
- U = disutility of using mode *pm* for the trip from origin *o* to destination *d*
- o = index for origin functional zone
- d = index for destination functional zone
- tp = index for trip purpose respectively goods category
- pm = index for passenger respectively freight transport mode

The logit function contains a disutility function (see) for each origin-destination pair, trip purpose respectively goods category and transport mode that is composed out of generalised costs and a constant called residual disutility.

$$U_{o,d,tp,pm}(t) = GC_{o,d,tp,pm}(t) + RD_{o,d,tp,pm}(t) \qquad \textbf{eq. 3-10}$$

where:
- U = disutility of using mode *pm* for the trip from origin *o* to destination *d* and trip purpose *tp*
- GC = generalised cost of using mode *pm* for the trip from origin *o* to destination *d* and trip purpose *tp*
- RD = residual disutility - constant specific of trip purpose *tp* mode *pm*
- o = index for origin functional zone
- d = index for destination functional zone
- tp = index for trip purpose respectively goods category
- pm = index for passenger respectively freight transport mode

In order to compute the transport flow matrices for each available transport mode, the resulting mode-specific probabilities are multiplied with the demand for passenger and freight transport that is provided by the REM in form of origin-destination (O/D) matrices per trip purpose respectively goods categories. Based on the classification of trips into five passenger and four freight distance bands, the modal split is performed for each distance band with different sets of available transport modes. In the passenger modal split model, the shortest distance band (LC) allows the decision between slow modes (walking or cycling), car and bus while the long distance band (LG) covers car, bus, train and air mode.

Initial traffic flows for the year 1990 were derived from information from SCENES (ME&P 2000) and ETIS (NEA et al. 2005) matrix for the year 2000. Based on observed trends between 1990 and 2000, these matrices were transformed into 1990 values and implemented as initial values for each distance band.

Cost and time matrices required for the computation of generalised costs per O/D and trip purpose depend on influencing factors like infrastructure capacity and travel speeds both provided by the Infrastructure module, composition of vehicle fleets, transport charges, fuel price or fuel tax changes. Resulting traffic flows determined by the modal choices, allow the estimation of transport expenditures that are used as an input in the MAC module. Considering average mode-specific distances per O/D-pair, load factors and occupancy rates respectively, the model is able to estimate the vehicle-kilometres-travelled (VKT) per transport mode. In order to integrate observed developments of load factors and occupancy rates due to significant fuel price increases, load factors and occupancy rates are supposed to improve with growing fuel prices.

Outputs of the TRA module impact elements of the MAC, FOT, Environment (ENV) and Vehicle Fleet (VFT) module. Based on traffic flows and the composition of vehicle fleets from the VFT module, the ENV module calculates the emissions from transport with the help of vehicle-specific emission factors. Besides emissions, fuel consumption and, based on this, fuel tax revenues from transport are estimated by the ENV. Traffic flows and accident rates for each mode form the input to calculate the number of accidents in the European countries. Expenditures for fuel, revenues from fuel taxes and value-added-tax (VAT) on fuel consumption are transferred to the macroeconomics module and provide input for the economic sectors producing fuel products and for the government model.

3.2.6 Infrastructure Module

The main objective of the Infrastructure (INF) module is the simulation of the development of transport networks and their capacity for the different transport modes. As the TRA module does not depict the transport assignment, infrastructure investments derived both from the economic development provided by the MAC and from infrastructure investment policies alter the infrastructure capacity. Using speed flow curves for the different infrastructure types and aggregate transport demand, the changes of average travel speeds over time are estimated and transferred to the TRA where they affect the modal choice. As origin and destination are for international trips not always within one country, all possible origin-destination combinations are stored in a transit matrix with probabilities. Together with the average travel times per section the total average travel times can be estimated. Furthermore, the INF module distinguishes at least for road and rail modes between short and long distances such that average travel times are differentiated for each distance band.

3.2.7 Vehicle Fleet Module

The main objective of the Vehicle Fleet (VFT) module is the simulation of motorisation trends and the description of technological composition of vehicle fleets. Each road mode besides motorbikes is considered in single models such that the development of vehicle fleets of passenger cars, buses, light duty vehicles (LDV) and heavy duty vehicles (HDV) in EU27+2 countries can be simulated. Passenger car fleets cover all passenger cars lighter than 3.5 tons, LDV all vans respectively trucks from 3.5 to 7.5 tons and HDV all trucks heavier than 7.5 tons. The core element of all vehicle fleet models is similar as all models simulate the vehicle fleet stock via level variables that are increased by new registrations and decreased by scrapping. New registrations of buses, LDV and HDV are driven by replacement of scrapped cars together with the demand for new vehicles derived from vehicle-kilometre-travelled provided by the TRA module for each mode. Based on average mileages per vehicle category, all three models deduce the registration of new vehicles. As all three level variables store and differentiate vehicle stocks by age, the model is able to compute scrappings depending on the age of the vehicle. In the calibration process, the parameters for scrapping of cars that reached a certain age are optimised. The LDV model differentiates between vehicles with in each case one diesel and one gasoline engine category. HDV are usually equipped with diesel engines such that this model distinguishes only between two loaded weight categories: less than 12 tons and more than 12 tons. Bus fleets are not further disaggregated. Additionally, all new registered vehicles are assigned to emission standard categories according to the registration year.

The most comprehensive fleet model in terms of influencing factors and number of car categories considered is the passenger car model. The former passenger car model differentiated between two car categories: gasoline cars with less than 1.4 litre cubic capacity, gasoline cars between 1.4 and 2.0 litre, gasoline cars with more than 2.0 litre, diesel cars with less than 2.0 litre and diesel cars with more than 2.0 litre. Comparable with bus, LDV and HDV fleets passenger cars are assigned to emission category standards according to the registration year starting with pre-Euro standard up to Euro 5. For example, passenger cars purchased between 1992 and 1996 would be assigned to Euro 1 standard. The following general equation represents the vehicle stock cohort model for all four road modes.

$$V_{i,c}(t) = \begin{cases} NRV_{i,c}(t) - V_{i,c}(t-dt) \rightarrow c = 0 \\ V_{i,cp}(t-dt) * (1 - SP_{i,c-1}) - V_{i,c}(t-dt) \rightarrow c \in [1,24] \end{cases} \qquad \textbf{eq. 3-11}$$

where:
- V = number of vehicles in country i and age cohort c
- NRV = new registered vehicles
- SP = scrapping probability of car in age cohort c
- dt = integration time step to previous point of time
- i = index for EU27+2 countries
- c = index for cohorts 0 to 24

The major difference between the structure of the passenger car model and commercial vehicle fleet models is constituted by the simulation of new registrations and car technologies. As opposed to commercial vehicle fleet models, new passenger car registrations are not driven by vehicle-kilometres-travelled. New car registrations are supposed to be dependent on the development of average income per employee derived from the MAC module, trends for average fuel prices and other costs for operating a car and the demographic development provided by the POP module. Empirical analysis confirmed that the development of average income per employee constitutes the most important impact on new car registrations. Together with a calibrated replacement share of scrapped cars, the number of new cars per year is computed. In a second stage, the decision of car purchasers for one of the five car categories is simulated. Factors like average car prices, vehicle taxes, fuel costs per car category and a fashion factor representing irrational reasons for buying induce changes of the initial share of new car purchases per car category observed in statistics.

3.2.8 Environment Module

The main objective of the ASTRA Environment (ENV) module is to estimate all transport-related environmental burdens in each functional zone respectively EU27+2 country. Additionally, all necessary information for assessing impacts of these burdens on economies are provided by the ENV module. Environmental impacts covered by the ENV module can be allocated into two categories according to the effects: global impacts and impacts on human beings. Not least the growing awareness of climate change as an unchangeable matter of fact demonstrated the global impacts of the greenhouse effect. Carbon dioxide (CO_2) emissions contributing up to 26% to the effect and, accordingly, can be considered as the most important greenhouse gas. Environmental impacts of transport activities on health of human beings can be direct effects such as the risk of traffic accidents but also indirect effects caused by emissions of nitrogen oxides (NO_x), resulting in ozone formation or soot particles (PM_{10}).

The main input for the ENV module is provided by the TRA module in terms of vehicle-kilometres-travelled and traffic volume per transport mode. Based on this information CO_2, NO_x and soot particles emission quantities are simulated for each EU27+2 country and all transport modes. As the ENV module derives complete life-cycle emissions caused by transport-related activities, four distinct sources of emissions are considered: hot emissions which occur during the driving activity, cold start emissions that are emitted during the warm up phase of vehicles starting with cold engines, fuel production emissions that exhaust during filling and production processes of consumed fuel and vehicle production emissions which occur during the manufacturing process of new vehicles. Apart from relevant information on transport performance, the composition of vehicle fleets is the second important input that is transferred by the VFT module. Based on the chosen differentiation of car categories and emission standards, average emission factors were integrated reflecting the transport activity and fuel and vehicle transformation related effects. For hot and cold start emissions, specific average emission factors per vehicle category and emission standard were derived from the Handbook Emission Factors for Road Transport (HBEFA 2004). The number of originating trips provides the necessary information for cold start emission calculation. Fuel production emission factors representing CO_2 and NO_x emissions caused by the extraction of crude oil from the ground, the transport of crude oil to refineries, the refining process and the transportation of fuel to the end-user has been taken from LEWIS (1997). Vehicle production emissions of average vehicles per car category were extracted from SCHADE (1997).

Emissions of other transport modes are modelled similarly. For example, rail transport performance is split into diesel and electrical traction and based on emission factors of power stations representing the national electricity mix CO_2 and NO_x emissions are computed. Air transport emissions could be simulated by considering average emissions of short and long distance flights of two representative aircraft types (Boeing 737 and Airbus A310).

Additionally, traffic accidents are estimated based on vehicle-kilometres-travelled per transport mode and mode-specific accident rates.

3.2.9 Welfare Measurement Module

The welfare measurement module provides tools for scheme-based and non-scheme based assessment. Scheme-based assessment aggregates single indicators which are synonymous to certain model variables according to a predefined scheme into one or a few aggregated indicators. Non-scheme-based assessment either uses directly the output of certain model variables for assessment or applies simple mathematical transformations on the results of a single model variable, still keeping each variable separately or relating two model variables to each other.

Two major scheme-based assessment approaches focusing on economic assessment are currently implemented. The first is the calculation of investment multipliers which makes sense mainly for policies that include infrastructure investments. Then the multiplier is calculated as the ratio of increases in GDP divided by the investments both discounted by a commonly agreed discount rate (currently 3% as this is the value applied in Germany for national transport infrastructure planning, but this could be selected). For the investments to consider there would be two alternatives: first, only the direct infrastructure investments are considered. Second, since the model also calculates the changes of investments in vehicles and auxiliary transport infrastructure (e.g. cargo terminals) these can also be included in the amount of investment in the multiplier.

The second scheme-based assessment is the newly developed dynamic Cost-Benefit Analysis (CBA). The categories of costs and benefits in the dynamic CBA are the same as in conventional static CBA. In ASTRA, the core categories of CBA schemes from all over the world (e.g. US, Japan, Germany and United Kingdom) are considered. These are: transport user cost, time-savings, induced transport, investments, safety and environment. Additionally also employment impacts are included which follows the German national approach for transport infrastructure planning. Both, costs and benefits, are discounted in the same way as with the investment multiplier. However, the difference to static CBA is that for each indicator and for each category of costs and benefits the dynamic time path starting with the base year of the policy and ending at the defined time horizon in the future is calculated. First examples of dynamic CBA have shown that the results of the CBA, e.g. in terms of the CBA ratios, are not stable over time and that even the ranking between different policy options could change over time (SCHADE/ROTHENGATTER 2002). In the test version of ASTRA the dynamic CBA has been separated again into a separate Vensim® file to save computing time. It will be checked if it would be feasible after modelling is finalised to integrate the dynamic CBA again such that for each simulation automatically the dynamic CBA profile is generated.

The simplest form of non-scheme-based welfare assessment is to look at the development of final effect indicators. Final effect indicators would cover a list of indicators that are at the very end of an impact chain beginning in the transport sector where the transport policy is applied, transmitted to other market sectors where intermediate indicators are changed (e.g. sectoral gross value added) and ultimately affecting the final effects indicators. Ideally, the list of considered final effect indicators would avoid double counting. Examples of final effect indicators are GDP or disposable income (not both because of double counting), employment, total transport CO_2 emissions or accidents.

Two other non-scheme-based assessments would either calculate index-numbers for the time-path of the model variables or derive the percentage changes of a certain model variable between the base scenario and the policy scenario.

Finally, an assessment can be built on intensity indicators which is also a non-scheme-based assessment. In this case, two logically related variables are mathematically linked usually by a division, e.g. the division of total transport CO_2 emissions by total GDP leads to a number of CO_2 intensity per GDP measured in tons per million Euro.

3.2.10 Structural Categorisations in ASTRA

The following two sections explain the classification of economic sectors and the spatial representation used in ASTRA.

3.2.10.1 Sectoral Disaggregation

Sectoral disaggregation in ASTRA is based on the concept of NACE-CLIO sectoral coding system where NACE stands for the general industrial classification of economic activities within the European communities and CLIO for Classification and nomenclature of input-output. Both are used in EUROSTAT (2008b) statistics, though the CLIO system is especially designed to generate harmonised input-output tables for the EU25 countries since each country used its own national system e.g. in Germany with 59 sectors (STABA 1997) or in the United Kingdom with 102 sectors (CSO 1992).[7]

The NACE system corresponds to international classifications like ISIC (International Standard Industrial Classification), such that also data following these categorisations could be used, and is available as NACE with 17, 25 or 44 sectors. Three main reasons suggest using the NACE-CLIO version with 25 sectors (see following table): firstly, in ASTRA the use of harmonised input-output tables for the EU27+2 countries is of significant importance to reflect the economic interactions that are induced in all sectors of the national economies by influences of policies in those sectors that are directly related to transport demand. EUROSTAT provides such tables for the EU15 countries for 1995 (EUROSTAT 1998). For the EU10+2 countries, the harmonised input-output-tables for 1997 were derived from the Social Accounting Matrices (SAMs) which were established for the IASON project (Banse 2000). Secondly, the split into 25 sectors offers five sectors that are directly related to transport demand changes and that would be affected by transport policies. These sectors are sector 2 Fuel and Power Products influenced by private expenditures for fuel; sector 10 Transport Equipment affected by private car purchase and investments in any other kind of vehicles; sector 16 Building and Construction driven among others by investments in transport facilities (e.g. container terminals or stations) and transport networks; sector 19 Inland Transport Services influenced by expenditures for bus, rail, road freight transport and inland waterway transport; sector 20 Maritime and Air Transport Services affected by ocean ship transport and air transport. Thirdly, among the 25 sectors are already 9 service sectors which enable the model to take account of the ever increasing importance of services for the European economies.

[7] In recent years there are attempts to standardise the system of input-output tables by international bodies like UN or EUROSTAT e.g. with ESA the European System of National Accounts.

Table 3-1: Differentiation into 25 Economic Sectors in ASTRA derived from NACE-CLIO

Nr	Sector Name	Goods sectors	Service sectors	Market sectors	Directly transport demand dependent
1	Agriculture, forestry and fishery products	X		X	
2	Fuel and power products	X		X	X
3	Ferrous and non-ferrous ores and metals	X		X	
4	Non-metallic mineral products	X		X	
5	Chemical products	X		X	
6	Metal products except machinery	X		X	
7	Agricultural and industrial machinery	X		X	
8	Office and data processing machines	X		X	
9	Electrical goods	X		X	
10	Transport equipment	X		X	X
11	Food, beverages, tobacco	X		X	
12	Textiles and clothing, leather and footwear	X		X	
13	Paper and printing products	X		X	
14	Rubber and plastic products	X		X	
15	Other manufacturing products	X		X	
16	Building and construction			X	X
17	Recovery, repair services, wholesale, retail		X	X	
18	Lodging and catering services		X	X	
19	Inland transport services		X	X	X
20	Maritime and air transport services		X	X	X
21	Auxiliary transport services		X	X	
22	Communication services		X	X	
23	Services of credit and insurance institutions		X	X	
24	Other market services		X	X	
25	Non-market services		X		

This table presents the list of the 25 NACE-CLIO sectors. It is indicated which sectors belong to goods sectors that e.g. generate freight transport flows and which sectors are considered for services. Together goods and service sectors are used e.g. at a sectoral level to model trade relationships of the EU27+2 countries. The five sectors that are directly influenced by changes of transport demand are also marked. It should be noted that both via the exchange of intermediate products from other sectors to these five sectors and via transport cost changes affecting the supply of intermediate products from the five sectors to all other sectors, also all sectors will be influenced by changes in the transport system that might emerge on a level as detailed as a single OD-pair.

3.2.10.2 Spatial Differentiation

Representation of space is one of the most important issues for transport modelling that is best tackled by using detailed spatial zoning systems in which zones are connected by a detailed link-based multi-modal transport network. On the other hand system dynamics modelling is neither capable of handling a full transport network nor would computing capabilities be sufficient to calculate European transport network equilibrium with system dynamics software. Hence, defining a spatial differentiation that balances the requirements of these two constraints provided one of the most relevant tasks in ASTRA. The problem is solved by defining two different categories for spatial representation that are selectively applied according to the needs of each module. The first classification is the differentiation of countries. Current EU27 member states plus Norway and Switzerland are treated separately as countries with the exception of Belgium and Luxemburg that form one region such that this category consists of 28 entities. The second category is the assignment to functional zones. The 282 NUTS II zones of the EU27+2 countries are grouped into four different zone types per country for EU15 and two different zone types for the other countries. As not all zones exist in every country this amounts in total to 71 entities. For the purpose of grouping zones population density and the relative position of a zone within all zones of one country are selected as criteria. Firstly, population density seems to be reasonable as it determines most relevant transport characteristics e.g. high density zones can be expected to have competitive public transport by tram or metro while low density areas are more bound to car usage. On average train connections between two high density areas should be better than between two lower density areas etc. It seems that a differentiation into four functional zones would provide the minimum required information to cope with the needs of transport modelling. Therefore, the following categorisation of functional zones is set-up listed in order of decreasing population density:

- Metropolitan Areas (MPA);
- High Density Areas (HDA);
- Medium Density Areas (MDA);
- Low Density Areas (LDA).

Secondly, taking population density as the only and the same criteria for all countries would lead to some countries that would show representatives only in one or two of the categories of zones which means to loose potential differentiation as the matrices in ASTRA then would include many empty cells. Hence, the relative position within a country determines the further criteria for grouping zones such that e.g. for a country that would have exactly four NUTS-II zones each zone would belong to a different category of functional zone and the assignment would fit to a ranking of their zonal population densities.

Following these two criteria all EU15 countries besides Ireland and Denmark would show representatives in all categories. In Ireland only three functional zones are present while in Denmark only two are considered, leading in total to the number of 53 functional zones for EU15. For the New EU Members plus Norway and Switzerland a slightly different approach was chosen. The six smaller countries Slovenia, Malta, Cyprus, Estonia, Latvia and Lithuania were not differentiated into zones at all due to their limited size. For the other countries always a split into two zones is applied using GDP per capita as the main criteria. This led to the fact that always the capitals plus at maximum one further prosperous neighbouring zone were grouped into the same zone (MPA) while the other zones were grouped into the other zone (MDA). The following figure presents the location of NUTS-II zones and functional zones in EU27+2 countries.

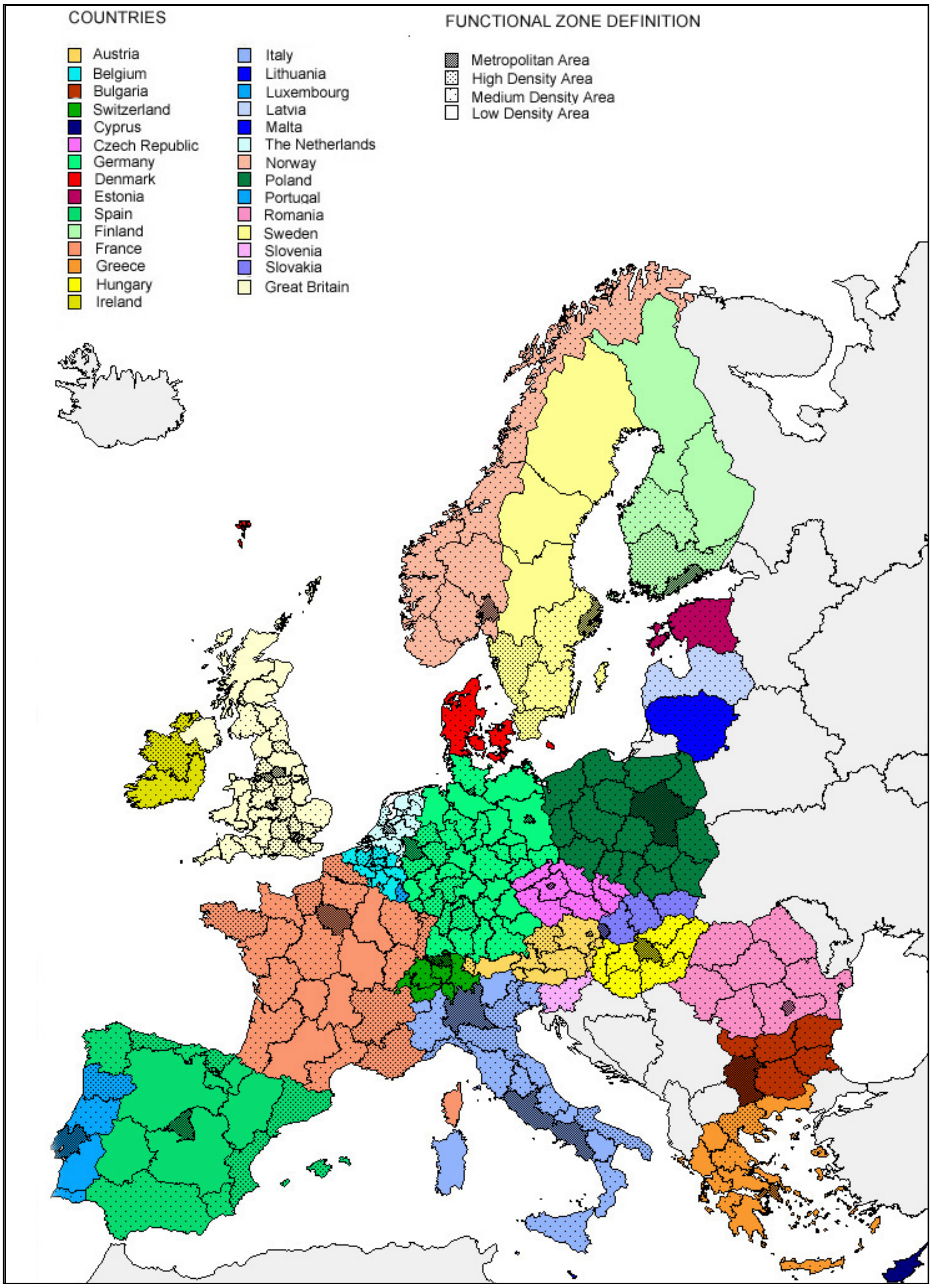

Figure 3-2: Overview of Spatial Differentiation in ASTRA

4 The ASTRA-S Model

In order to differentiate between the ex-ante status of the ASTRA model and the new version of ASTRA, the latter is denoted as ASTRA-S. The suffix "S" represents the social component which is intensified with the integration of the income distribution model in ASTRA. The main objective of this section is the description of the models that are developed and integrated in the ASTRA-S model for this thesis. New established models such as the household or income distribution model as well as models that are modified for the purpose of this thesis are presented. Additionally, underlying theories and existing approaches are described in order to support the understanding of the chosen modelling approaches. The section starts with an overview of the interaction of the new ASTRA-S models. In the following, the development of the single models under consideration of available theories, their structure and implementation in ASTRA-S is depicted. Finally, the section concludes with a description of the ASTRA-S calibration approach.

4.1 Overview of ASTRA-S Model Development

The introduction of this thesis pointed out the relevance of an enhancement of the ASTRA model. In order to enable the assessment of income distribution impacts on the basic mobility behaviour, several changes of the ASTRA model are required. Hence, this thesis centres on the development of new modules and modification of present modules for this purpose. As the prospective mobility of all income classes exceedingly depends on technological development of rolling stock, the simulation of technological change and the resulting environmental and economic impacts are considered as well.

The development of a model simulating income distribution trends has turned out to be the major challenge of this thesis. As the ASTRA MAC is a macro-level model, the simulation of complex coherences between socio-economic trends and income distribution is a demanding task. Nevertheless, the ASTRA model could provide valuable inputs for the endogenous simulation of income distribution and inequality.

Figure 4-1 illustrates the interactions between the modified and new established models. Furthermore, it demonstrates how the new models are embedded in the ASTRA module environment. Based on socio-economic data like GDP, provided by the MAC, or the demographic structure, provided by the POP module, the new household model simulates the development of households differentiated into five household classes. The main output of the new household model is the number of households per category. The household structure per country, demographic information from the POP module and labour market data from the MAC module form the main input of the new income distribution model. This model is integrated in the MAC module. The first model which integrates the new income distribution trends is the first stage of the classical four-stage transport model, the passenger trip generation model. In order to identify mobility patterns of persons in different income brackets, comprehensive analysis of European travel surveys is carried out. The trip generation model reflects the mobility behaviour under consideration of further socio-economic inputs from the POP and MAC module. For a more detailed simulation of trip generation, the spatial differentiation of the population model is enhanced to administrative regions on NUTS2 level.

As the income distribution model allows a more detailed insight in the income situation of the population, the resulting income distribution constitutes a value-added for the modelling of car fleets as well. Saturation effects limiting the number of new car registrations can be derived from income distribution.

Both models, the new income distribution and the revised car fleet model, directly impact the following stages of the four-stage transport model. The distribution of trips to every imaginable destination in EU27+2 countries is influenced by the trip generation and the modal split model considers motorisation as driver of choice for the mode car. Finally, resulting transport performance, costs and times induce changes in the MAC module.

In parallel, the estimation of technological development of passenger car fleets is improved. Alternative car technologies are integrated and a new established technology choice model reflects individual car purchase decisions for a certain technology. Together with the resulting mobility behaviour, the technological composition of car fleets provides major inputs for the computation of transport-related emissions.

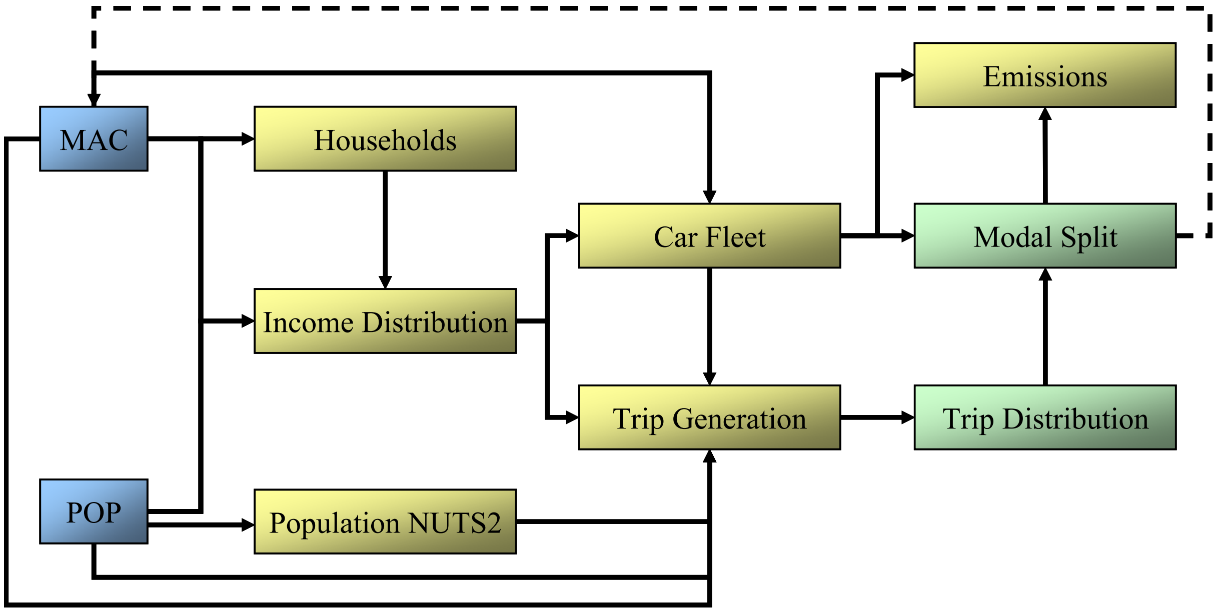

Figure 4-1: Overview of Interrelation of New Established Models in ASTRA-S

4.2 Household Model

The household model simulates the previous and future trend of the number of five household types for each of the EU27+2 countries. The decision to develop a model projecting future household structures for the purpose of this thesis was mainly based on the hypothesis of scientists like HARRISON/BLUESTONE (1990). They identified the household structure, especially the number of single parent households, as an important driver of income inequality (see section 4.3.1.3).

Regarding the modular composition of ASTRA-S, the new household model is integrated in the POP module. For the period from 1990 to 1999, empirical data on the development of the number of households per household type can mainly be extracted from the online database of EUROSTAT (2008a). As some countries are not represented in this database, data is derived from the statistic departments of the respectively countries. Considering the period from 1990 to 1999, clear statements can be made requiring a closer look at the influencing factors and the development of the number of households in the future. A strong overall increase of single households can be observed while households of couples with children tend to decrease in almost all EU27+2 countries. This fact leads to the intention of the household model: A change in the structure of the different household types takes place over time. The aim of the model development is to show these dynamics of change and the trends that follow.

The first stage in the household model development is the determination and definition of the considered household types. As most of data sources like Eurostat categorised the household structure data into five different household types, these are adapted for the ASTRA-S household model. This classification allows for a comprehensive simulation of the household structure over all EU27+2 countries. Technically, the number of each household type is modelled in a level variable. Hence, the number of households per household type is determined by its base year composition, yearly inflows and outflows. Many factors influence either only one type of household or all of them.

The household type single (*Single HH*) stands for a household consisting of only one person without children or partner. The number of Single HH decreases over time by the formation of couples or communities and the death of single persons. It is supposed to increase by the formation of new singles e.g. children leaving their parents home or students leaving communities, the separation of couples and the death of a partner in a couple household.

The second household type is constituted by single parents (*Single Parent HH*). The number of Single Parent HH is considered to decline caused by reformation of families like the so-called patchwork families and children leaving single parents. The level of Single Parents HH grows with new single parent induced by separation of parents.

The third implemented category of households is couples without children (*Couple wo Children HH*). Their number decreases by separation of couples, death of a partner and new parents. They increase by formation of couples, separation of other households, further transfers and last child leaving home.

Additionally, the model differentiates households of couples with children (*Couple w Children HH*). They change negatively by separation of parents, when the last child leaves its parents' home and when children of couples become adults. Positive changes are supposed to be caused by reformation of families, new parents and separation of other households.

The category of other households (*Other HH*) which includes households with more than two adults with or without children decreases by formation of single and separation of other to couple and family households. Furthermore, it increases by the number of single parents with adult children, the new formation of communities and couples with children that become adults. The following figure illustrates the chosen structure for the household model with five level variables representing the number of households per household type and respective inflows and outflows.

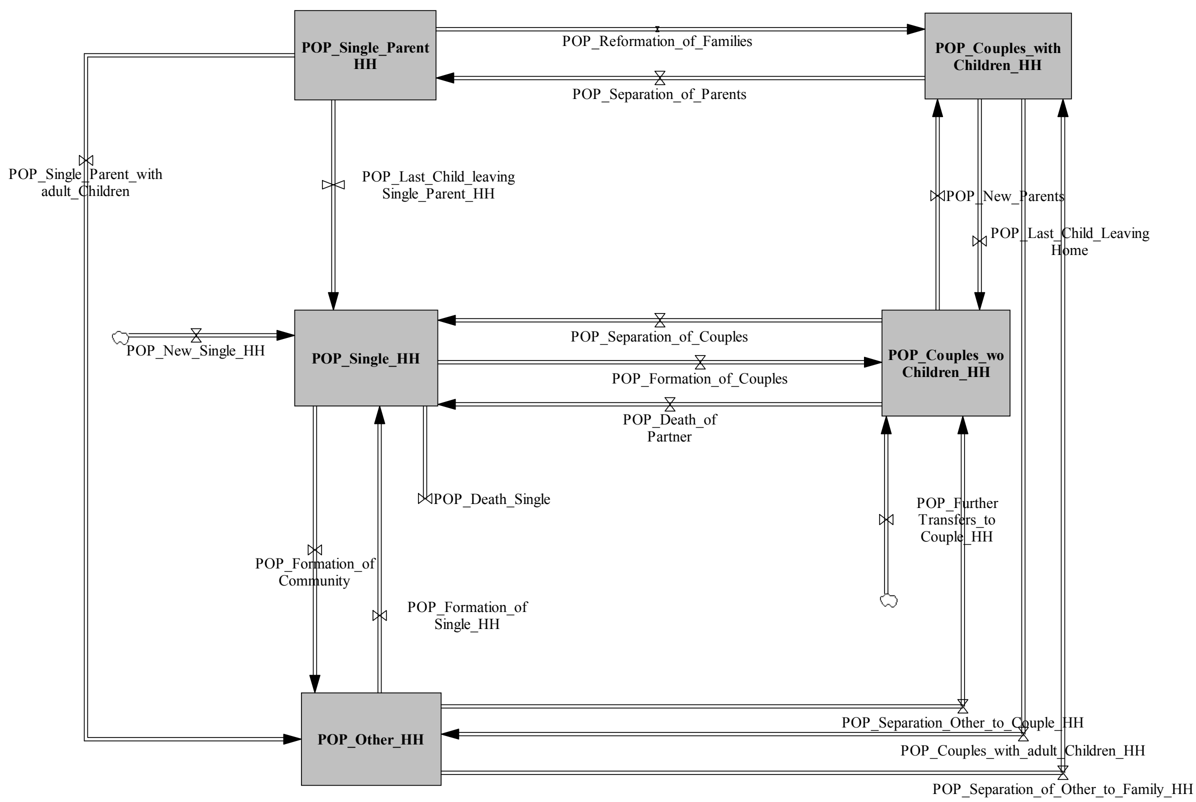

Figure 4-2: Structure of Household Model

After the categorisation of the five household types and the assignment of system components according to the System Dynamics nomenclature, the most important factors influencing household structure development are analysed. A first attempt of identifying the direct impacts of endogenous socio-economic factors such as gross domestic product, demographic structure and urbanisation on the change of the quantity of households has failed. The reason for that is that there are no realistic courses that explain that these three factors lead to one variable 'delta households' that is distributed to the five household-types or any correspondence to the statistics except from small deviance. Hence, a regression analysis between the main factors and the individual household-types brings a further argument of the missing correlation. In addition, there is no sufficient explanatory power of the factors to the development of the households except from one. An alternative examination of the change between the individual household types by analysing divorces and marriages results in a different conclusion. Divorces concern the population from 30 to 55 years and the marriages the population from 20 to 40 years. To state the correspondence between the metric interesting variable divorces and the explaining variables gross domestic product, urbanisation and age structure a multiple regression analysis is realised. The output is significant: the coefficient of determination is about 0.81 which means that 81 % of the diversification of divorces can be explained by linear dependency on the three socio-economic factors. A multiple regression analysis between marriages and these three factors supports the correspondence by having a coefficient of determination of 0.98. The simple regression analysis between divorces and population conducts coefficient of determination of 0.76 and the consideration of marriages and population a coefficient of 0.98. Simple regression analysis between divorces respectively marriages and gross domestic product plus urbanisation does not lead to the required output. Outlier data delays the regression line so that the coefficient of determination does not have any explanatory power.

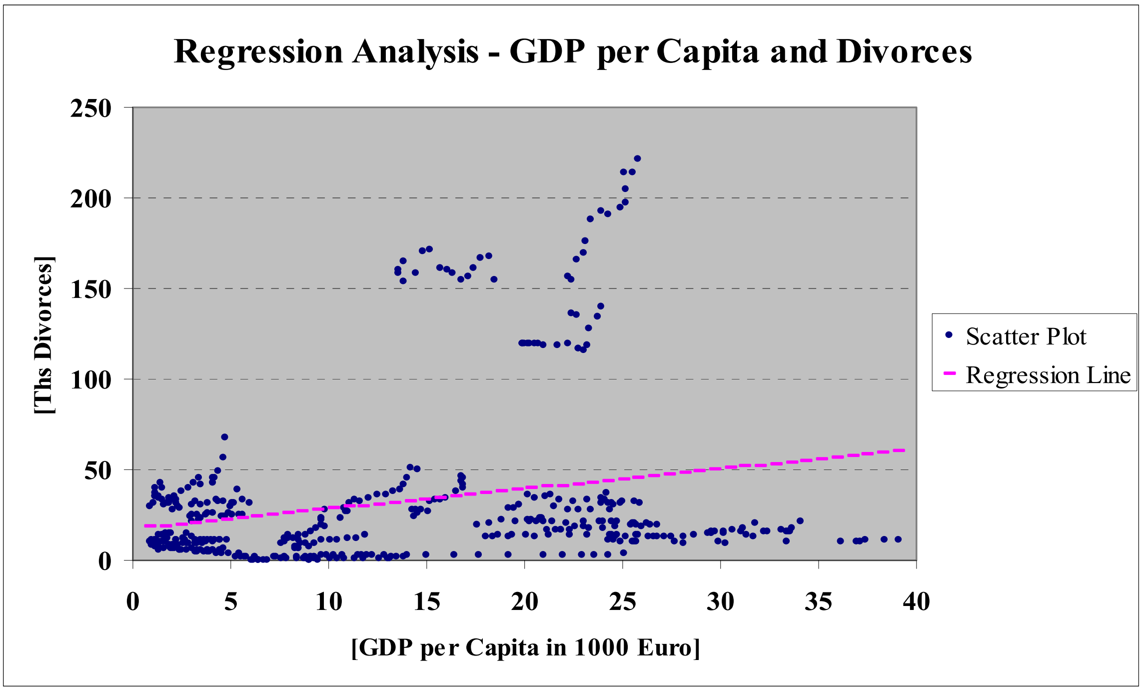

Figure 4-3: Regression Analysis between GDP per Capita and Divorces

The correlation analysis between divorces respectively marriages and changes of the quantity of households lead to the variables *Potential Separations of Couples* and *Potential Formation of Couples* which influence the inflows and outflows between single and couple households. These variables are based on the number of yearly divorces and marriages which are influenced by a yearly number of changes that rely on change rates. The Potential Separation of Couples is directly influenced by the change of divorces. The following equations (eq. 4-1 and eq. 4-2) demonstrate the calculation of potential separations respectively formation of couples:

$$DIV_i(t) = DIV_i(t-1) * (\Delta potDIV_i(t) * \alpha_i + \Delta Urb_i(t) * \beta_i + \Delta GDP_i(t) * \gamma_i) \qquad \textbf{eq. 4-1}$$

where: *DIV* = number of divorces per year
ΔpotDIV = delta population between 30 and 55 years
ΔUrb = delta urbanisation
ΔGDP = delta GDP per capita
α = coefficient for impact of population change (30-55) on divorces
β = coefficient for impact of urbanisation change on divorces
γ = coefficient for impact of welfare change on divorces
i = index for EU27+2 countries

$$MAR_i(t) = MAR_i(t-1) * (\Delta potMAR_i * \alpha_i + \Delta GDP_i * \beta_i) \qquad \textbf{eq. 4-2}$$

where: *MAR* = number of marriages per year
ΔpotMAR = delta population between 20 and 40 years
ΔGDP = delta GDP per capita
α = coefficient for impact of population change (20-40) on marriages
γ = coefficient for impact of welfare change on marriages
i = index for EU27+2 countries

Apart from the considered impacts of marriages and divorces on potential new couple respectively new single households, endogenous variables like births, deaths and the number of children between 18 and 25 years, determine all other intersections between household types and inflows into respective outflows from household types. Figure 4-2 illustrates the simplified structure of the household model in the typical Vensim® notation. It hides all auxiliary and constant variables that are implemented to provide the input for all flow variables. Nevertheless the household model is dominated by flow and level variables. Most flow variables constitute inflow and outflow at the same time. Therefore, they determine the intersection of a household from one household type to another. Furthermore, there are some flow variables that are defined only as inflow respectively outflow. For example, deaths are modelled as an outflow from Single HH. For simplification reasons, deaths are considered as outflows from Single HH, Couples wo Children HH and Other HH, as these are the typical living conditions of ageing people. In the second case, the death of a partner in a Couples wo Children HH leads to a transfer of the remaining person into a Single HH. Deaths of people living in one household with two or more adult persons (Other HH) cause by a calibrated probability to a transition into both couple household types. Another inflow into Single HH was necessary as adult children which leave a couple or a Single Parent HH might not inevitably lead to a transfer of one Single Parent HH into two Single HH respectively Couple w Children HH into one Couples wo Children HH and one Single HH. This is only the case when the last child leaves its home but not when one child stays in the parents' household. The average number of children per family is used to estimate the probability that the last child leaves home. All other flow variables represent transfers from one household type to another. All transfers are described in the following paragraph.

An important transfer from couple to single household types is caused by separation of couples respectively parents. They are determined mainly by the number of potential new couples. At a second step they are distributed to separation of couples without children and with children via a calibrated share. In this context it has to be mentioned that all calibration parameters can be altered in the calibration process within a predefined range. This range is derived mainly by empirical observations from national statistics offices or determined by expert judgement. New couple formations or reformations of so-called patchwork families constitute the second important transfer between single and couple households. The potential number of separations is derived from the number of divorces is the main driver for both flow variables. The transfer between households without and households with children depends on the number of births and the probability that the baby is the first child of a couple. The model considers only couple households for this transfer, as Single Parent HH are rather uncommon in this status according to statistics. The estimation of the last child leaving a parents' home is based on the average number of children per family and the number of potential children leaving home between the age of 18 and 25. This variable provides the intersection in the other direction, from households with children to households without children. A differentiation was made between children and adult children because a formation of a new household is not determined by children turning into an adult because of the educational status.

Transfers to the type other households are on the one hand the parental households with adult children that come from a single parent household and couples with children households. On the other hand single persons living together which means the potential children leaving home and potential students living together in one household. The exogenous fraction of students on total number of population between 18 and 29 years, derived from the education database of EUROSTAT (2008a), multiplied by a factor that reflects the part of students forming a community provides the potential students living together. Transfers from Other HH are assessed by the number of formation of singles and separation to couples and families. Formation of singles is defined by the number of students that split back to single households after studying on average four years and a factor of miscellaneous outflow. The separation from Other HH to Couples wo Children HH is influenced by a factor of deaths of Other HH and a factor reflecting the probability of a three-person household. The separation to Couples w Children HH expresses the so-called patchwork families that are formed basically from single parents.

4.3 Income Distribution Model

In the following section the structure and the elements of the new income distribution model are presented. The latter is integrated in the ASTRA-S Macroeconomic (MAC) module. The income distribution model is established in order to allow the analysis of income distribution impacts on passenger transport performance. In the beginning, characteristics of historic explanatory approaches of income distribution are depicted and analysed. Then, the development of the income distribution model framework is demonstrated. After describing the data availability and existing constraints for the model development, the paragraph shows the process of identification and analysis of influencing indicators. The section concludes with the quantification of impacts on income distribution.

4.3.1 Theory of Income Distribution

The main objective of this section is to introduce the reader to the theory of income distribution in order to ease understanding the chosen income distribution modelling approach. Therefore, the chapter begins with an explanation of the term "income" as used in economics. Different categories of income are described, followed by a depiction of common methods for the measurement of income inequality and income mobility. The introduction to this section concludes with a presentation of explanatory approaches of income distribution.

4.3.1.1 Overview of Income in Economics

In colloquial, the term "income" is usually associated with monetary inflows of a person or a household during a certain period of time. Several definitions of the term "income" can be referred to in this context, but the following definition provides a comprehensive description of the term:

> *"Income is the sum of all the wages, salaries, profits, interests payments, rents and other forms of earnings received[...] in a given period of time."* (CASE/FAIR 2007, p.54)

This general definition of the income does not presume a regularity of monetary inflows and is derived from practical experience. As the income distribution model is implemented in the framework of a macroeconomic model, the meaning of income in economics is focussed in the following pages.

In macroeconomics as well as in microeconomics, income can be considered as a central welfare indicator. Generally, private households and firms are distinguished in economics. Private households and persons provide production factors such as property, labour and capital to firms. Income of private households is gained by wage compensation of all offered production factors. Income can be differentiated into four categories (FRENKEL/JOHN 1999):

- *earned income* by employed persons (wages and loans),
- *gained income* by self-employed persons (gains, rents, etc.),
- *capital income* (interests, dividends, etc.) and
- *transfer income* (social benefits, etc.).

The first two categories can be assigned to income from employment. Income from employment in combination with investment respectively property income is defined as *primary income* or *factor income*. It indicates the origin of income from the three production factors. Disposable income of private households is determined as factor income plus all transfers after-tax. The national accounting framework provides information about the interrelation of income and goods flows. Figure 4-4 illustrates the definition of income in the context of National Accounting Framework derived from STLA RLP (2005, p.5).

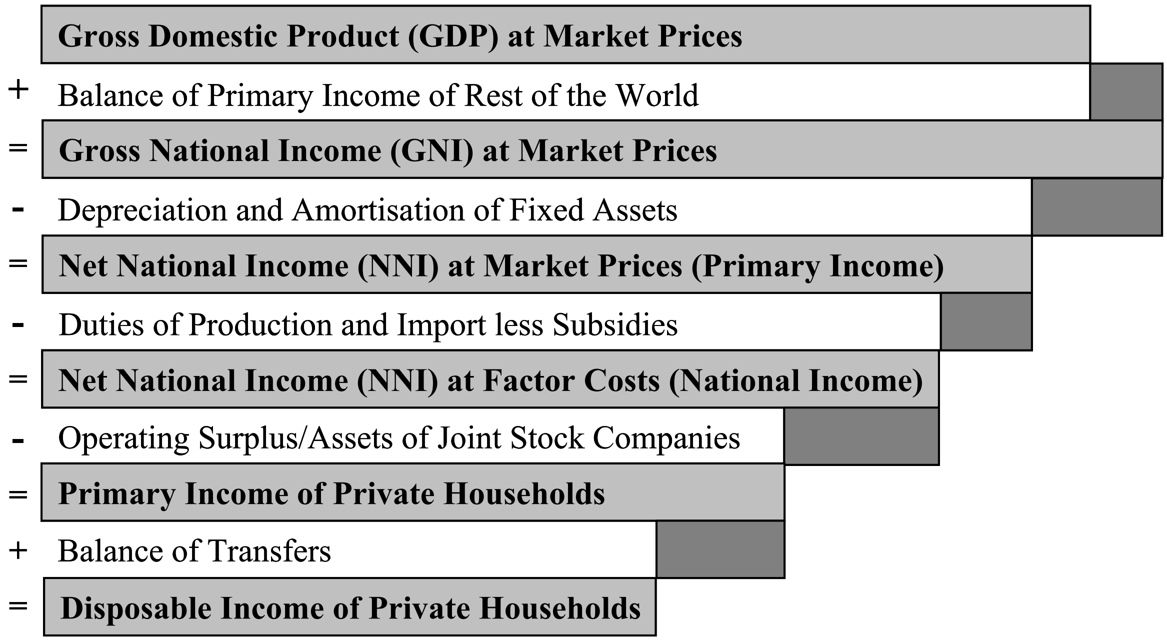

Figure 4-4: Income Terms in the Context of National Accounting Framework

The structure of the ASTRA Macroeconomic (MAC) module follows the national accounting framework in terms of the calculation of disposable income based on the gross domestic product (GDP). The level of disposable income can change over time due to inflation or deflation. Hence, all monetary values in the ASTRA MAC module are defined in real terms by division through an adequate pricing index. BOL (2004) describes this approach in detail, whereas in the meantime chain indices are applied (StBA 2007, p.5). In order to be able to compare monetary results, GDP-deflators from Eurostat are used in the ASTRA MAC module as pricing index.

Regarding the distribution of income two principle categories can be distinguished: *personal income distribution* and *functional income distribution*. In functional income distribution, wages, gains and capital income are put in relation to net national income at factor costs. On the contrary, personal income distributions give insights on how the total disposable income is distributed among persons or groups of persons. As this thesis addresses income distribution impacts on mobility behaviour, the personal income distribution approach is considered in the following.

In connection with income distribution *income inequality* has to be looked at. Based on the scientific field in which income analysis is performed, the focus is different. In sociology, the analysis of structural, social inequality derived from differences in accessibility of economic resources is highlighted. In economics, the focus is on efficiency and equality. In the following context, income inequality is considered in a descriptive sense.

4.3.1.2 Measuring Income Inequality

There are different approaches for characterising income distribution. The next section presents an assortment of the most practical ones. Another paragraph is about the overview of the different classes of measurement methods. Three major groups are distinguished:

- location and variance parameters,
- extents of inequality and concentration and
- extents of distance and mobility.

The first two classes focus on a distinct moment of time. The last one shows differences during time periods.

Location and Variance Parameters

Amongst the location and variance parameters, there are indicators such as the *arithmetic mean*, the *range*, the *quantile*, the *standard deviation* and the *coefficient of variation*. The only parameters with an acceptable force of expression within asymmetric distribution are quantiles. Quantiles separate the integrated density function in equal parts. Quantiles can be divided into several types according to the number of parts in which for example the total population is distributed. Quartiles with four parts, quintiles with five parts and deciles with ten parts are the most common ones. In case of arranging the income from lower to higher income the first quintile shows how high the highest income of the poorest fifth truly is. Quantiles do not show the distribution within the quantile, that is why the relation of quantiles can be used as a measurement parameter. Figure 4-5 illustrates the 0.5-quantile of a right-skewed frequency distribution.

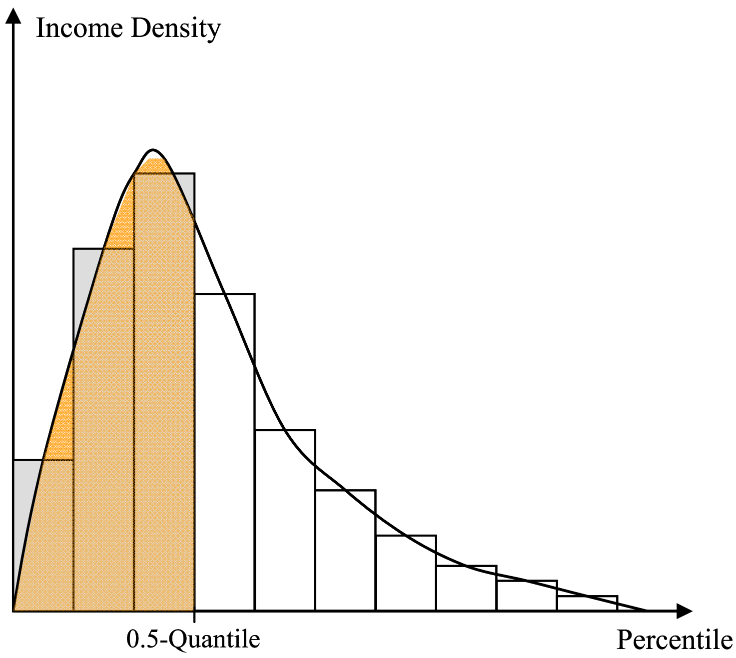

Figure 4-5: Right-Skewed Frequency Distribution with 0.5-Quantile

Extents of Inequality and Concentration

Extents of inequality and concentration show how equal the income is distributed on a given number of people. The base is stratification of the income from low to high. As a graphical description the *Lorenz-Curve* has a dominating role. If there are *n* recipients of income with the income y_k the *k* lowest incomes can be aggregated and normalised. The values of the ordinate are:

$$v_k = \frac{\sum_{i=1}^{k} y_i}{\sum_{i=1}^{n} y_i}$$ **eq. 4-3**

where: v = ordinate value
y = income
n = number of income recipients
k = number of persons with lowest incomes

On the axis of abscissas the values are $u_k = k/n$. The result is a curve that shows which part of the observed people obtains which percentage of the whole income. Ergo, the Lorenz-Curve is a convex and monotone increasing curve starting at point (0,0) and ending at point (1,1). In case of a complete equal distribution, the bisecting line and the Lorenz-Curve are exactly the same. The higher the concentration the larger the difference between the two curves. The extreme case of one person getting the whole income is shown by a triangle between (0,0), (n-1/n/ n, 0) and (1,1).

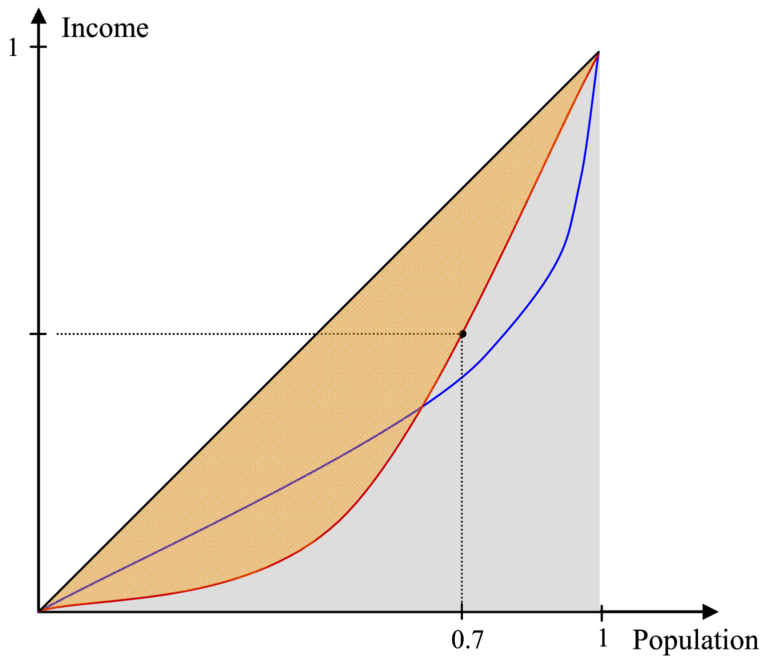

Figure 4-6: Lorenz-Curve and Gini-Coefficient

Based on the Lorenz-Curve, the *Gini-Coefficient* shows the grade of concentration in only one number. Adopting values between 0 (equal distribution) and 1 (complete inequality), the Gini-Coefficient is calculated by the relation between the plane inside of the bisecting line and the Lorenz-Curve and the triangle ((0,0), (1,0), (1,1)). Problems can be found in the fact that the Gini-Coefficient takes more care about the transfers in the middle income area than in the border area. It is also problematic that different distributions can lead to the same coefficient. Hence, the question when the inequality of one distribution is higher then the inequality of another one is quite interesting. Due to the orientation to the equal distribution, there is a value judgement (AIGNER 1993, p.42). Considering aspects of welfare, one can tell about the domination between distributions with the help of generalised Lorenz-Curves (SHORROCKS 1983). Multiplying the shares of the middle income part of the Lorenz-Curve leads to the generalised Lorenz-Curve (AIGNER 1993, p.55). The higher Lorenz-Curve is dominating in case of no intersection.

The advantage of the *Theil-Index* is the decomposability which means that the index values of the partial group will be added to the index value if the whole group. Based on the analogy of the information theory, the Theil-Index shows the grade of information. If the manner of different information $i = 1,....,n$ with the likelihood $y = \{y_1,....,y_n\}$ and $\sum y_i = 1$ in an information source has different likelihoods, the less appearing information will get a higher value $h(y_i)$. This claim will be fulfilled by $h(x) = ln\ (1/x)$. Hence, the expected value of information of a source is the sum $H(y)$ of each piece of information, weighted by the corresponding likelihood.

$$H(y) = \sum_{i=1}^{n} y_i \cdot h(y_i) = \sum_{i=1}^{n} y_i \cdot \ln\left(\frac{1}{y_i}\right) \qquad \textbf{eq. 4-4}$$

where: H = expected value of information of a source
y = likelihood
n = number of different information
h = value of a single information

Hence, the entropy is maximal if the likelihoods for the appearance of the single information are equally distributed. Interpreted as shares of single persons' incomes, this parameter shows the equality of the income distribution. To obtain an index for the unequal distribution, the maximal value *ln(n)* has to be subtracted by the previous equation. The result is the Theil–Index (COWELL 1995, p.47).

$$T = \frac{1}{n} \cdot \sum_{i=1}^{n} \frac{y_i}{\bar{y}} \cdot \ln\left(\frac{y_i}{\bar{y}}\right) \qquad \text{with } \bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i \qquad \textbf{eq. 4-5}$$

where: T = Theil-Index
y = income
n = number of income recipients
$\bar{y}$ = average income

Because of assumed utility functions for the poor and rich people, the favoured ideal distribution is the equal distribution (BLÜMLE 1975, p.46). The most used normative dimension is the *Atkins Dimension*. At first, the "equally distributed equivalent level of income" (ATKINS 1970, p.46) has to be regarded. Marked by as the average income of a distribution, the following Atkins Dimension is the dimension for the inequality. This is the share of income which is not needed to achieve the current welfare. The Atkins Dimension can reach the same values like the Gini-Coefficient. All mentioned dimensions are part of the "Generalised Entropy Family" which are based on moments of distributions (STICH 1998, pp.7).

$$I = 1 - \frac{y_e}{\bar{y}} \qquad \textbf{eq. 4-6}$$

where: I = Atkins Dimension
y_e = equally distributed equivalent level of income
$\bar{y}$ = average income

Extents of Distance and Mobility

The last indices examine the income distribution in a certain period. To explore the differences between the groups or distributions in different periods, the values of extents of inequality can be compared. Hence, there is only the comparison of aggregate data and not of all the detailed information. This allows no statement about the mobility of the income. In order to enable a more detailed analysis the following extents of distance and mobility are useful.

Based on the Atkins Dimension, Shorroks proposes the distance *d(X,Y)* as the difference between the level of welfare of distribution *X* and *Y* (AIGNER 1993, p.75).

$$d(X,Y) = |X_e - Y_e| \quad \textbf{eq. 4-7}$$

where: *d(X,Y)*= difference between the level of welfare of distribution X and Y
X,Y = normalised distributions

Ebert appointed the distance without using utility functions. The base of $d^{\gamma}(X,Y)$ is the comparison of the income quantiles. The parameter γ is free of choice (AIGNER 1993, p.76).

$$d^{\gamma}(X,Y) = \left[\sum_{i=1}^{n} \frac{1}{n} \cdot |x_i - y_i|^{\gamma}\right]^{\frac{1}{\gamma}} \quad \textbf{eq. 4-8}$$

where: *d(X,Y)*= difference between the level of welfare of distribution X and Y
X,Y = normalised distributions
x,y = income
n = number of income recipients
γ = parameter, free of choice

As a generalisation of the Lorenz-Curve, this difference of the values of the density function provides details about the disparity of the belonging distributions. The spare between the cumulated difference and the graph in case of identical distributions of *X* and *Y* can be assumed as an index in the same way as the Gini-Coefficient (AIGNER 1998, p78). The three mentioned extents are inequality reduction extents. Therefore, it is difficult to obtain the information about how many people have changed the level of income.

The extents of transition matrix mobility are only able to measure income mobility. The base is the change between the income classes which is described in the mobility matrix (number of changes in income classes since the last measurement). Hence, the transition matrix which contents the likelihood p_{ij} with $\sum p_{ij} = 1$ for $i=1,...,k$ for changing the class can be estimated. The assumption of the likelihood for the change is based on the approach that the elements of the transition matrix are the results of a random experiment. The assumption is that the likelihood of change is related to a *Markov-Chain* which does not consider the history of an income recipient. Under certain conditions, the result is the maximum likelihood estimator for the content of the transition matrix (TREDE 1996, p. 6).

$$\hat{p}_{ij} = \frac{n_{ij}}{n_i} \quad \textbf{eq. 4-9}$$

where: $\hat{p}$ = maximum likelihood estimator
n = element of the mobility matrix

There is the possibility to calculate different kind of extents of mobility. One example is the *Index of Bartholomew*. In this approach the average change is used as an extent of mobility, whereas higher changes are weighted higher (TREDE 1998, p93). All mentioned extents for the measurements of the income distribution have advantages and disadvantages. Today, people talk about functional and personal theories of distribution.

4.3.1.3 Explanatory Approaches of Income Distribution

There are many approaches that give an explanation on how income distribution comes off. Literature simply differs clearly between macroeconomic distribution theory and approaches for explanation of personal income distribution. The latter admittedly is a *"relatively unstructured side by side of theoretic concepts"* (GRÜSKE 1985, p.47).

In order to understand the context of personal income theories, historical development is being outlined in the following. Subsequently macroeconomic distribution theories are described, because personal income distribution always comes along with the functional distribution and large socioeconomic groups respectively. In order to understand the scope of the existing models, the theories of personal income distribution are explained, divided into income diversification and income level[8]. They considerably restrain to (gross) earned income. The design is made in reference to the significance of the approaches in the appropriate literature. The focus lies on procuring the basic thoughts of the different approaches[9]. Long-term development models are described in an own paragraph. Redistribution is also considered separately. Given that this work develops a simulation model, the following section ends with an outline about simulation models.

Historical Context

Ricardo was the first representative of the classic political economists dealing with income distribution (BLÜMLE 1975, pp.1). Substantial, the distribution to the social groups like landowner, entrepreneur and labourer are interesting[10]. Marx and the Socialists only differentiate between capitalists as owner of the production factors and unpropertied labourer. Just as the classics distribution theory bases on price-theoretical considerations.

Within neo-classic a factor-orientated view is developed, whereas distribution comes from payment of the production factors according to their marginal productivity under the assumption of perfect competition and full employment of all production factors. Today, a distinction is drawn between functional and personal income theories. On account of the "authority of dispose" of the production factors there is coherence between the payment and income distribution to individuals. This connection comes from the crosswise distribution which shows that the income of an income recipient can derive from the possession of more than one production factor (SCHMITT-RINK 1978, pp.114). ASIMAKOPULOS (1988) provides a comprehensive description of the historical context.

Macroeconomic Distribution Theories

Whereas the (microeconomic) marginal productivity theory advanced to the macroeconomic marginal productivity theory, further theories were developed which base on the socialistic approach or explain distribution by demand. BARTMANN (1981) and KÜLP (1981) offer a detailed description of these theories. The coherency of these *macroeconomic proportion models* are clarified in Figure 4-7 which is derived from the description of BLÜMLE (1975). The Marx constitutive power-theories (e.g. Kalecki and Mitra) argue with different

---

8 This approach follows the steps in Blümle (1975)

9 Most approaches were developed between the 1950ies and the 1980ies. Hence, the considered literature was written in these years. Recent papers and studies are usually based on well-known ideas. The only difference is given by increasing complexity.

10 In the 3-sector-model income is separated into loans, gains and basic pension. In the 4-sector-model gains are further differentiated into profits and interest on capital.

negotiation power of enterprises and employees. Consequently, enterprises can put through a higher mark-on than in the neo-classic model. With Keynes distribution theories came up that base on the demand behaviour (et al. Kaldor and Pasinetti). In contrast to the production- and respectively supply-orientated view of the neo-classic model these theories are circular flow-orientated (BLÜMLE 1975, pp.5).

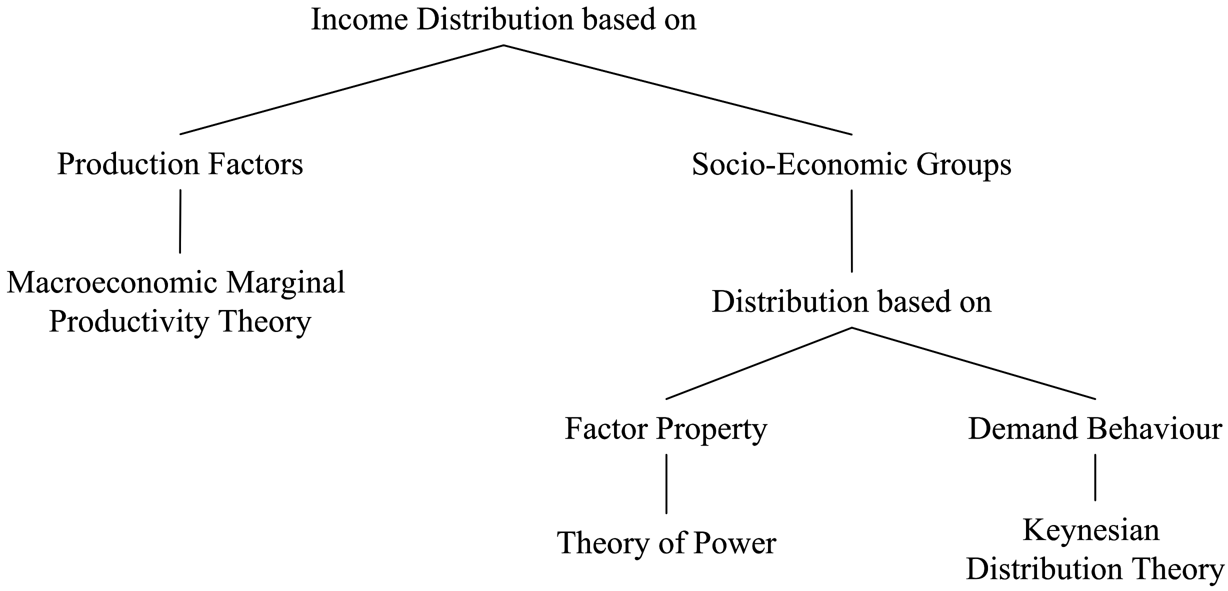

Figure 4-7: Overview of Macroeconomic Distribution Theories

Explanation of the Frequency Distribution

Personnel distribution theories demonstrate approaches for the explanation of the income level and the *"diversification of the income by height"* (BLÜMLE 1975, p.13). There are many partial-models with the intention to explain frequency distribution of the income whereas the focus lies on the earning income. The following paragraph gives an outline about the central ideas that underlie these concepts.

Stochastic Models

Generally - under the assumption of a representative sample - a right-skewed frequency distribution can be observed for different income distributions (see Figure 4-5). Pareto tried to describe these coherencies by the following function:

$$N = b * y^{-\alpha}$$ **eq. 4-10**

where: N = number of persons that receive an income of y or more
y = income of a person
b = parameter

Plotting the relative cumulated frequencies of the particular income with the help of a double-logarithmic coordinate system, the *Pareto-Line* can be obtained. The linearity can only be applied to high income (see Figure 4-8) (KLEIBER 2000, pp.79).

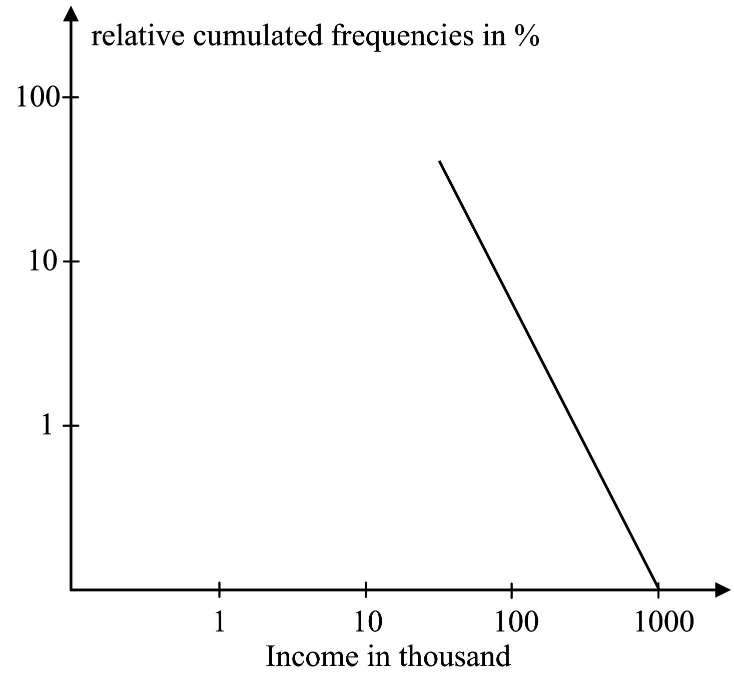

Figure 4-8: Pareto-Diagram

Income distribution can be considered as conclusion of a coincidence process whose income level depends on distribution of certain characteristics on the income recipients. Are these characteristics normally distributed and multiplicatively connected, an income distribution of a logarithmic normal distribution is resulting. Generally, this performance can be observed empirically (LYDALL 1981, pp.127). The appropriate approaches can be qualified as Ability-Theories. The approach of Roy illustrates an example for these theories (RAMSER 1987, p.29).

Likewise, under specific conditions, the assumption that the current income only depends on the income of the previous period (Markov-Chain) can lead to a logarithmic normal distribution (BLÜMLE 1975, pp.49). Overall, the *stochastic models* may be able to indicate the income distribution but they do never provide an economic explanation for the development of a distribution.

Choice Models

On the contrary, *choice models* devote income distribution as distribution-balance of supply and demand of workplaces (BLÜMLE 1975, p.77). The most cited distribution-balanced model is the Tinbergen model[11]. The underlying idea of the model consists of workplaces being characterised by requirements and labour being characterised by its skills. With the help of appropriate payment there ought to be an optimal assignment between employees and function (TINBERGEN 1956, pp.158). The requirements and skills can be present in different levels. Which working place (assumed that the demand of work is given) is chosen by who depends on the individual function of utility. Furthermore, it is assumed that *"there is a shortage of high qualified persons related to the corresponding positions, and it relates to (non-) economical rationality to employ overqualified persons"* (WEGNER 1981, p.60). Hence, there will be persons with a qualification below the requirement of the working place. This fact leads to strains between requirements and skills. In special conditions there is the

[11] As different model versions exist, the model described in TINBERGEN (1956) was chosen.

possibility to explain that approach with a lognormal distribution of the earnings. However a few of these assumptions are estimated as problematic (BLÜMLE 1975, p. 80).

Sorting Models

The approach of the model of choice assumes that the skills of employees are given. In case of no information about these skills, the modeller has to collect that information to find an optimal choice. *Sorting models* explain how these relations can be created (TAUBMANN 1981, pp.116). Employees learn during education and work about their skills and how to apply them. Due to the growing experience they are able to sort the different activities according to advantages. Ergo, they exclude some jobs and might change their working place to a better one with more advantages (NEAL/ROSEN 2000, p. 392). The education can be seen as a *"signal of the true skills of a person"* (TAUBMANN 1981, p.116).

Human Capital Models

The Ability-theory assumes that the skills of the persons are the key to the income distribution. The category of *human capital models* assumes that most attributes and skills of a person are partly given by birth or by nature. But the large part of the skills (for instance education) can only be gained during lifetime. Due to the dependence of the income distribution on this human capital, the major question is who gains this education and what the reason for it is. This is the main question of the human capital theory. The central thesis relates to the assumption that the investment of people in education is driven by optimisation. Investments in human capital are:

> *"…activities that influence future monetary and psychic income by increasing the resources in people. The many forms of such investments include schooling, on-the-job training, medical care, migration, and searching for information about prices and incomes. […] All these investments improve skills, knowledge, or health, and thereby raise money or psychic incomes."* (BECKER 1964, p.1)

The simple model of Mincer assumes that the skills given by birth are the same for everyone and that everyone is free in the choice of employment. The length of education depends on the chosen employment. Due to the costs of education and the abandonment of today's income, the future income has to be higher to compensate that cap. Every economic agent is faced with the optimisation problem according to the investment calculation of the enterprises to maximise the capital value of the investment in education. Thereby complete information and constant income during the professional life is assumed (MINCER 1958, pp.284).

This approach is enlarged by BECKER (1964). He states that the investment in human capital can last several years and that the length can hardly be estimated. Consequently, the investment costs are equal to the loss of income and consist of *"the real difference (during the investment period) between […] (the activities with and without compulsory education) and the loss of income of the past periods caused by investments"* (ZACHER 2003, pp.42). The return of education can be seen as the internal rate of return of the periodised net values of the investment in education comparing activities with and without education (ZACHER 2003, pp.40).

Hierarchic Models

Another approach to explain the income distribution is via *hierarchic models*. They try to obtain the information about the level of income of the bureaucratic structure in companies, the main focus on explaining the origin of the Pareto distribution and the income in the higher levels (WEGNER 1981, p.94). Both LYDALL (1969) and BECKMANN (1974) deduce the distribution from the geometric increase of income during an increase in the hierarchic structure and geometric decrease of the number of persons in the hierarchic levels. Differences can be found in the explanations. Lydal takes the fact that a superior takes care for the *"same average number of subordinates"* (BLÜMLE 1975, p.66) as given. Beckmann has another explanation for the geometric decrease. He talks about the typical structure of a company which explains the constant control margin. This is the result of the statement that a superior has *"beside his own activity the control as a major activity*" (BLÜMLE 1975, p.66).

Beckmann advices to *"choose a constant share of income (per person) between the different levels"* (BECKMANN 1974, p.138), to create a constant incentive to upgrade, having regard to the decreasing marginal utility. Lydal explains this fact with the increasing responsibility during the hierarchic upgrade. The responsibility of a superior can be measured with the sum of the income of his subordinates. The results are geometric increasing salaries, due to the geometric decreasing occupancy of the increasing hierarchic levels (BLÜMLE 1975, p.67).

Models Explaining Distribution of Capital Income

The recent models explain only earned income from working activities. BLÜMLE (1972) tries to explain the distribution of the income caused by assets in a formal similar way as the hierarchic models. *"He generates a Pareto distribution with the help of geometric decreasing income caused by assets during time and at the same time a decreasing number of people getting the income"* (POHMER 1985, p.30). The assets of a person depend on the original assets, the interest rate, the saving rate and the elapsed time. The origin assets are created by heritage assuming that at every time the same number of people obtains the same origin assets. In case of constant rate of dying assets holder the result of the level of incomes is the number of people receiving a heritage and still living. The result is a *Pareto Distribution* (BLÜMLE 1975, pp.70). In case of an increasing product of interest rate and saving rate there will be an increasing inequality. The concentration shrinks with an increasing death rate at the same time. This model is based on a few critical assumptions und does not take any single economic decisions into account (POHMER 1985, pp.31).

Life-Cycle Models

Even in case of constant basic conditions there is an income variation during the lifetime of a person. One attempt to explain this is given by the *life cycle models*. The personal distribution is a result of an individual utility maximisation during the whole lifetime (RAMSER 1987, p.54). The life cycle model created by Blinder was *"the first attempt to explain the distribution of periodic income and life time income with the help of the microeconomic intertemporal factor supply"* (POHMER 1985, p.54). In case of complete information each subject is trying to maximise the utility of consume, free time and assets. The utility functions assume decreasing marginal utility und that future utility will be discounted. The economic subjects decide about consume and time spent for work. The assets are changing during lifetime, because of work, savings and consume. The sum of working time and free time has to be equal to the available time. The level of salary is given exogenous (POHMER 1985, pp.54). In this model there are no decisions about investment in human capital. In a correct way, the modeller can relate to POHMER (1985) and his integration of the theory of life cycle and human capital. He *"assumes a population which maximises the utility. The people decide with the help of skills given by birth, preferences and origin assets"* (RAMSER 187, p.65). Another life cycle model was created by WEIZSÄCKER (1987).

Insurance Models

Another approach to explain the income distribution is via *insurance models* respectively *risk preference models*. As an important representative of these models, FRIEDMANN (1953) deduces a characteristic right-skewed distribution based on the different risk preference of the receptors of income. A basic condition therefore is a certain insecurity of the incomes. For the risk-averse individual, faced to the same risk, it could be worthwhile to assure against undesirable events (RODGERS 1981, p.232). Risk-averse persons are willing, *"in case of income fluctuation, to assure themselves against income diversification – they will change a higher unsafe income against a lower safe income"* (POHMER 1985, p.35). However, this phenomenon can rarely be found in reality because of *"moral hazard and adverse selection"* (NEAL/ROSEN 2000, p.413).

4.3.1.4 Explanation of Level of Income

Most models of the last chapter explaining income distribution can also be used to allocate the level of income. Furthermore, there is a socio-economic influence on the level of income. Especially the coactions of different variables[12] seem to be important (BLÜMLE 1975, pp.86). As mentioned in the other models, there are factors which are limited and individually influenceable (GRÜSKE 1985, p.53).

Socio- Economic Constants

According to BLÜMLE (1975) the following variables are not individual:

- sex,
- race,
- age,
- skills given by birth and
- social background.

In many cases, one can prove a correlation between these *"socio-economic constants"* (BLÜMLE 1975, p.87) and the level of income. A differentiation between skills given by birth and influences by the environment is difficult. The influences by environment are stronger and the measurement is more precise. One should recognise that the observed correlations are not necessarily based on causalities. Examples are the creation of assets, experience and mobility. They are in general related to the age and there is a justification about the connection of the level of income (GRÜSKE 1985, p.58). The effects of these factors on the income are caused by *"the society in which a person lives"* (BLÜMLE 1975, p.88).

[12] Compare especially the Multi-Factor-Theories of LYDALL (1981).

Socio-Economic Variables

The characterisation of limited, influenceable factors is difficult. For sure, one of the main factors is health, decided on the one hand by genes and destiny and on the other hand by moral conduct, added by dynamic factors summed under *"personality"* and *"character"*. Furthermore the income is determined by a network of relations. The measurement of such influences is more or less difficult (GRÜSKE 1985, pp.60). More variables influenceable by single persons (BLÜMLE 1975, pp.92 and GRÜSKE 1985, pp.64) are:

- region,
- education,
- kind of job,
- personal utility function and
- readiness to assume risk.

Examples are different prices beyond the regions that induce different salaries beyond the regions. The choice of the place to live and work is in general free. At least the education depends on the parents' house. The decision about further education is not influenced by the parents. Furthermore, the kind of job and the individual utility function and risk preference influence the level of income. Overall a few of these factors are so called soft factors. Between those, independence is limited.

4.3.1.5 Long-Term Development

The presented partial models are showing facts about income distribution during constant economic and social background. These conditions can change on the long term. The major influences on the change of the income equality will be presented in the following chapter, based on a summing up of (GUSTAFSON/JOHANSSON 1999):

- economic development and /or size of the industrial sector,
- international division of labour,
- macroeconomic performance,
- reasons outside a strictly defined market sphere and
- demography

Growth and Kuznets–Hypothesis

The major opinion of the fact, if there is a relation between economic growth and income distribution and which kind of relation this might be, has changed a lot in the past years. After World War II there was a consensus, that industrialisation and growth reduces poverty. Between 1950s and 1970s people held the opinion that either growth or a low inequality can exist. In the middle of the 1970s the people thought that this conflict can be solved by an intelligent policy. Today, there are doubts about compatibility of economic growth and reduction of inequality (KAMBUR 2000, pp.794). There is an outline about reasons regarding a relation between income distribution and economic growth in STEWART (2000).

In the 1960's KUZNETS (1965) successfully estimated the development of income inequality in the US. His hypothesis states that societies in the industrialisation stage are characterised by increasing income inequality. A relation between economic development and inequality which is formed as a converse 'U' can be observed. The main reason for this is the transfer of working force between the primary (agriculture) and the secondary (industry) sector. At first, the coexistence of primary sector with low labour productivity and low wages and secondary sector with high labour productivity and high wages leads to increasing income inequality. In the course of industrialisation this inequality is equalised as the weight of the industrial sector grows.

> *"The income inequality is growing under the condition of a change of working force from the traditional sector to the modern sector (implies higher wages), after reaching a maximum, it is declining.*" (FRANZ 1997, p.15)

Apart from the transfer of employees from primary to secondary sector, Kuznets identified further reasons for increasing income inequality. He considered the growth of population as another driver, under the assumption that this results in increasing numbers of low-skilled workers.

The validation of Kuznets-Hypothesis is controversial (STEWARD 2000, p.5) and could only explain the income inequality trends in the US between 1925 and 1960. The so-called Kuznets curve illustrates the typical development of income inequality (see Figure 4-9). There is an equilibrium model proposed by GALOR/TSIDDON (1996) that describes the relation between income inequality and income per capita.

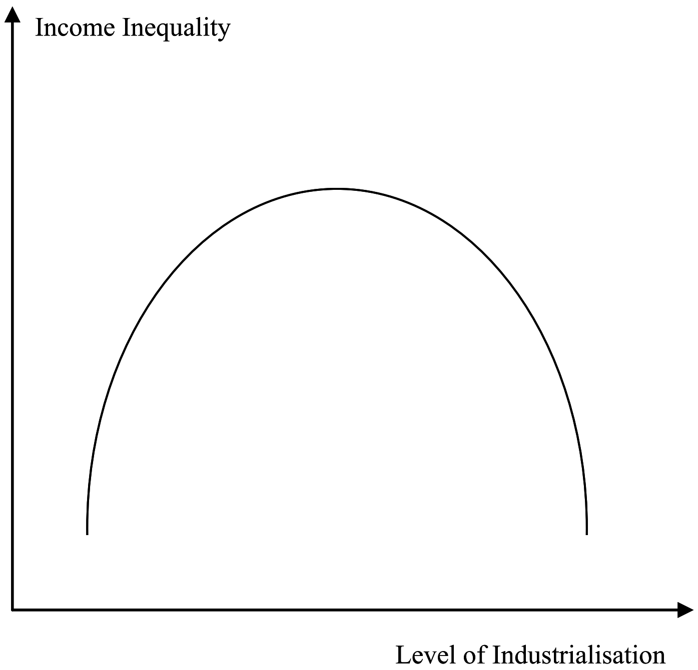

Figure 4-9: Kuznets-Curve

Related to HARRISON/BLUESTONE (1988), inequality will increase again in case of deindustrialisation. Caused by a higher level of wages in the industrial sector and heterogeneous payment in the service sector, income inequality is declining with a growing number of workers in the tertiary sector. Because of the "Great U-Turn"[13] the inverse 'U' turns into a '∩' (FRANZ 1997, p.16). Furthermore, Harrison and Bluestone identified other important drivers of income inequality. They considered the structure of households, most significant the number of single parent households, and the share of women in the labour market as further important drivers of income inequality. Impacts of these factors are obvious as average single parent households have less time budget to hold down a job and, according to statistics the share of part-time jobs is significantly higher for women than for men.

Education

Many explanatory approaches of income inequality regard education as an important driver. Originally, improving distribution of premium education was assumed to decrease income inequality. Economically, this effect was found with the growth of high-skilled employees that cause competition on high-skilled jobs. Finally, the competition leads to a reduction of wage differences between high-skilled and low-skilled employees. Today, experts like NIELSEN/ALDERSON (1972) confirm the importance of education in regard to income distribution and inequality. In contrast to previous attitudes, they identified the heterogeneity of education in a society as more significant.

Globalisation and Technical Progress

On the contrary to the explanatory approaches, a discussion on the role of trade and technology emerged in the US during the 1990's. According to their philosophy, economists split into two different positions and the consequence was that a discussion on "technology versus trade" appeared. Half of the experts considered that trade of industrial nations with economic less developed nations can lead to a higher income inequality, because of the differences in the level of income between these nations.

> *"Increased trade of manufactured goods has exposed less qualified workers in industrialised countries to more competition which in turn has pushed their wages down."* (GUSTAFSSON/JOHANSSON 1999, p.587)

To argument in an alternative way, one can assume that the cause for the loss of work places is in the secondary sector. The income inequality is inclining in this case because of the *"less-paid compensation work places in the service sector, compared to the lost ones in the industry"* (FRANZ 1997, p.20). Among others, KRUGMAN (1996) points out that trade with less developed countries is rather unimportant as it was on a level about 3 % of US gross domestic product during the 1990's. Hence, he expressed doubts about the impact on American wage structure respectively income inequality.

Apart from the liberalisation of markets, technical progress can also be seen as another cause of globalisation (LAMMERS 1999, p.11). Hence, there is a further reason for growing income inequality. Requirements of workers are increasing because of technical progress. *"Many of the averaged paid work places are at the same time less paid or even not any more vacant"* (FRANZ 1997, p.18). Criticism was passed on this theory as technical progress was considered in nearly all studies as residual variable. Regarding the development of labour productivity in the US the explanation significance of technical progress on income inequality is rather low.

[13] Harrison and Bluestone chose this title for their book.

Macroeconomic Development

Another point is the conjuncture which influences unemployment and inflation. Thus, there is an influence on the income inequality (GUSTAFSON/JOHANSSON 1999, p.587). Typical fluctuations of income and the share on the conjuncture circle are explored by CREAMER (1956) and METCALF (1969).

Institutional Factors

Another influence is based on institutional factors of the labour market which can be explained by the influence of labour unions and labour agreements supplemented by influences of the political and economical system, especially the measurements of the state concerning security at the work place and the size of the public sector (FRANZ 1997, p.19 and GUSTAFSSON/JOHANSSON 1999, p.588).

Demographic Factors

The last point is the change of income inequality based on the change of the demographic structure. Changes of the share of parts of the population (e.g. retired persons) combined with changes of the behaviour (e.g. growing number of female employees) can also change income inequality.

4.3.1.6 Redistribution

Taxes and Transfers

There are only explanations for the distribution of the gross income. The disposable income is based on the level of taxes and transfers, defined by law. The normative base of an optimal choice of a transfer and tax system is provided by the distribution policy which is not considered in this thesis.

Regime of Welfare State Policy

This section presents a possibility of a choice of different systems concerning volume and effect on the redistribution. ESPING-ANDERSEN (1990, pp.26) found three different typical regimes of welfare state policy separated by social security depending on the market. In the group of liberal states of welfare policy the overbalance is on a moderate state benefit, supporting only the lower income classes after testing. Conservative states of welfare policy offer a system of social security with keeping the eye on the differences between the statuses. According to ESPING-ANDERSEN (1990, p.27), the state's emphasis on upholding status differences means that its redistributive impact is negligible. The social democratic welfare state emphasises universal programs with a high distribution effect. There are high, partly income-based, benefits and the spectrum of the covered risk is wide (BIRKEL 2005, p.2).

4.3.1.7 Simulation Models

Most approaches explained in the past paragraphs are resolvable in an analytical way. There is the possibility to integrate these ideas in simulation models. The eligibility of the different approaches will be discussed in section 4.3.2. The following chapter will give an outline of simulation models in economics.

The main objective of simulation models in economics is the simplified representation of real systems and their behaviour, in order to allow the analysis of different scenarios with this model. Based on the model results estimations can be made on most probable future development of real systems (SPAHN ET AL. 1992, p.6).

One possibility of the differentiation of simulation models is the aggregation level. *Macroeconomic models* and *general equilibrium models* have the highest level of aggregation. The former describes the economic circle of income (SPAHN ET AL. 1992, p.7). General equilibrium models consist of equations, describing the behaviour of supply and demand, allocation and distribution, and conditions of the equilibrium on factor and good markets as well as macroeconomic aggregates (Bork 2000, p.63). Because of their aggregation level, both categories of models are originally not adequate for a comprehensive analysis of income group dynamics.

Group simulation models have a lower level of aggregation. These models take a look at homogeneous socio-economic groups with certain relevant classification criteria (SPAHN ET AL. 1992, pp.7). An example is the effect of a change in tax policy on different types of households. Group simulation models are created in a simple and transparent way. The calculation effort is not that high but the volume of such a model grows fast with the consideration of more criteria, caused by the multiplicative influence of the number of groups. Another point is that people in a group have to be nearly equal to be represented correctly with a characteristic group. A desegregation of the groups is not possible. Hence, all criteria have to be considered at the beginning. The membership of a group and the criteria are constant during the duration of the simulation (BORK 2000, pp.67). An example for a group simulation model is the model of KRUPP (1981, p.194). Based on a given function of a distribution, Krupp models the distribution of different factor incomes on households. The latter are fragmented in different groups based on socio-economic aspects and on possession of factorial assets. Income from property of production factors and from the structure of the factorial prices can be assumed based on the assets at the beginning. The terms of production factors depend on the disposition of the income (e.g. creation of assets) and the transfer of the factors (e.g. heritage). The structure of the factors prices declares the achieved prices of a group of households related to the average prices of the factors. There is proportionality between the factorial assets and the structure of the factor prices. Furthermore, there is an average addition of fluctuations considering the different saturation of the factors by different households (KRUPP 1981, pp.194).

Micro-simulation models constitute the lowest level of aggregation, based on micro-analytic approaches which lay stress on micro units like households or individuals. The method handles typical individual cases or a sample of micro units (SPAHN ET AL. 1992, p.9). This approach is based on

> *"…the attribution of economic and social processes, observed in reality, on micro units which are acting individual. Hence, the approaches of explanation of the identification of aggregate variables or individual effect of political measures should be implemented at the determined factors.*" (BORK 2000, p.70)

Information on the structure can be considered because of the limitation of individual cases. At the same time, the calculating effort of the simulation is manageable. Due to the empiric orientation it is not possible to take into consideration and analyse all mechanisms of action. To cope with the whole population the sample has to be representative and adequately weighted (BORK 2000, pp.70). The model described by BORK (2000) belongs to the group of micro-simulation models.

4.3.2 Modelling of Income Distribution

The objective of this section is to present the structure of the implemented income distribution model. At the beginning, the development process is reflected which led to the final model framework. In the following the considered approaches and their adaption will be depicted based on the analysis of available and significant drivers of income distribution and income mobility. This section will clarify the reasons for the choice of the single impact parameters and, thus, the chosen structure of the model.

4.3.2.1 Requirements on Income Distribution Model

As the main objective of this thesis is the analysis of income distribution impacts on mobility patterns, the choice of the structure of the income distribution model is mainly influenced by the requirements set by the characteristics of the chosen passenger transport modelling approach. Section 4.4 illustrates the analysis of mobility surveys which leads to the structure of the implemented passenger trip generation model in the ASTRA-S Transport (TRA) module. In the context of this analysis, the needs in terms of structure and output of the income distribution models are determined. Regarding the objective of this thesis and the destination models in which the outputs of the income distribution model should be used as inputs, the personal income distribution approach is chosen.

The second question which has been answered during the planning stage is the following: Would a model reflecting the development of incomes per population quantiles or a model simulating income mobility between income groups with fixes income ranges fulfil the requirements in a better way? Both structures are conceivable, as the British National Travel Survey (DFT 2006) analyses the mobility patterns of population quantiles in the Great Britain, while the German Mobility Panel (see KUHNIMHOF 2007) considers the mobility patterns of households with different monthly income ranges. The decision for the latter structure is based on the fact that comprehensive and adequate mobility surveys are performed only in few European countries in the past years. Therefore, another constraint has to be taken into account: the mobility patterns derived from one or more mobility surveys have to be transferred for all other covered European countries. Regarding the different levels of income inequality in Europe, the framework using mobility patterns of income quantiles derived from the British National Travel Survey (NTS) is not applicable. The framework representing the number of people per fixed income ranges adapted from the German Mobility Panel (MOP) remains as capable basis. Hence, the simulation of personal income mobility between fixed income groups becomes the main task of the income distribution model. Modelling this dynamics can answer the question on how many people earn between x and y Euro per month in the future.

As the MOP indicates mobility patterns per income group for households, the optimal way to model the level variables is to refer them to households and not single persons. Regarding the application of outputs in the passenger trip generation model, this framework supports a sophisticated analysis of passenger transport performance. On the other hand, the model output should be used as well to estimate the demand on further car registrations in the ASTRA-S Vehicle Fleet (VFT) module. For this purpose, the number of persons per income group is more meaningful. An income distribution model providing the number of households per income group can only be used, if all households in each income group can be further differentiated into the household type which reflects the number of persons per household. Without this information, the output cannot be used for the estimation of prospective car registrations. Unfortunately, this differentiation of households cannot be realised as elaborate data and information on the assignment of households with certain incomes to different categories of households (described in chapter 4.2) has not been available. Thus, the income distribution model relates to income ranges of persons and instead of households.

Regarding the choice of income types considered in the income distribution model, another need is derived from the structure of the applied mobility survey. The MOP demands the panel participants to classify themselves into income ranges which should represent the monthly net income in terms of wages respectively salaries, self-employed income and income from transfers. As this definition excludes capital income, the consideration of capital income in the income distribution model would adulterate the assessment of impacts on mobility behaviour. Taking into account capital income would induce the allocation of a significant share of the population in higher income groups than without and lead to an overestimation of trips as persons in higher income groups are more mobile (see section 4.4.2.3).

The MOP distinguishes between eight different income groups. The ranges represent the monthly net household income and have a range of 500 Euro such that the first income group covers households with less than 500 Euro net income per month and the highest income group households with more than 3,500 Euro. As described in chapter 4.4.2.3 the trip rates of persons are derived from the original household based income groups. Regarding the resulting model structure with in total eight income groups, 28 transfers between the income groups representing the income mobility would be necessary. Even a reduction of transfers due to constraints such that persons are assumed to be able to decline or raise only two or three income groups within one period will still end up in a number of transfers that cannot be accomplished within such a model. Based on the analysis of numbers of persons per income group in the mobility survey, the number of income groups can be reduced to the following five:

- persons with low income (Low Inc),
- persons with low to medium income (Low-Med Inc),
- persons with medium income (Med Inc),
- persons with medium to high income (Med-High Inc) and
- persons with high income (High Inc).

Hence, the best possible model structure considers ten transfers between five income groups. Figure 4-10 presents this modelling framework of the income distribution model.

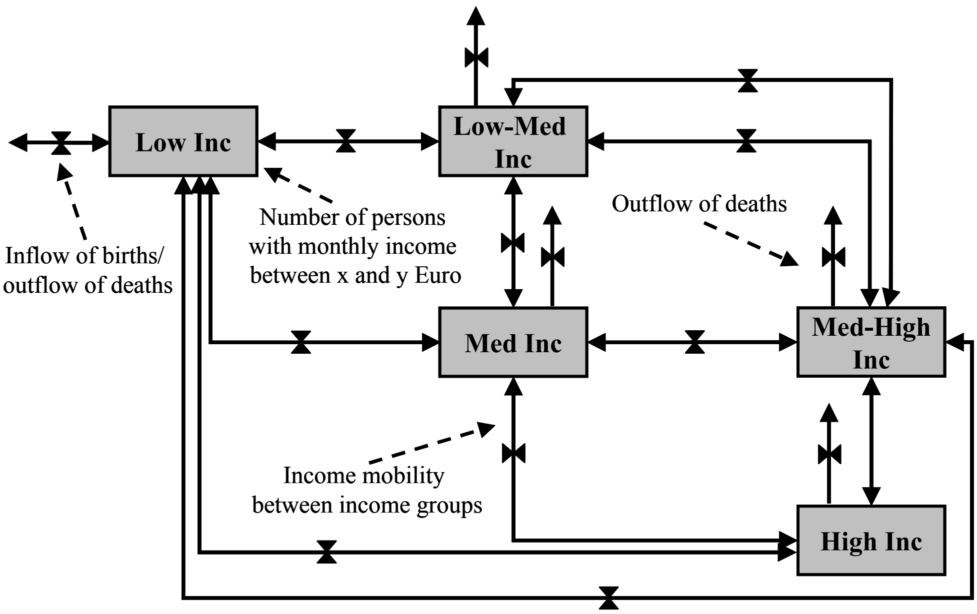

Figure 4-10: Overview of Income Distribution Model Structure

As described in section 4.4.2, results of the analysis of the MOP in terms of average trip rates per person in a certain income group per year have to be adapted for all other EU27+2 countries covered in the ASTRA-S income distribution model. The model assumes that the mobility behaviour is similar within the five income groups but the definition of the income range of the five income groups varies from country to country. Monthly net income bounds per person are estimated for each of the modelled EU27+2 countries based on the price index[14] for transport products and services of the country compared with the German price index. Table 4-1 shows the resulting income steps in nominal terms which lead to the income ranges of the five income classes. As an example, Danish persons with a monthly net income between 748 and 1.496 constant Euro 1995[15] are assigned to the second income group, the so-called "low-medium income" group (Low-Med Inc).

Table 4-1: Country-Specific Income Steps for Income Distribution in Euro 1995

Country	Income-Steps	Country	Income-Steps	Country	Income-Steps
AUT	533	GBR	575	SWE	594
BLX	494	**GER**	**500**	CHE	547
DNK	748	GRC	389	CZE	348
ESP	444	IRL	548	HUN	412
FIN	595	ITA	477	NOR	774
FRA	487	NLD	572	SLO	390

Apart from the test of the model structure for fulfilment of mentioned requirements, another factor impacts the choice of the final modelling framework. The complete model has to be validated in a calibration process in order to minimise the deviations from statistical values for the ASTRA-S calibration period from 1990 to 2005. Therefore, historical data from surveys or statistics has to be checked on availability for the chosen model structure.

[14] The EU27 price index for transport was derived from power purchasing parities of the Eurostat online database.

[15] All modelled monetary values in ASTRA are expressed in real terms and deflated to constant Euro 1995 with a Eurostat GDP deflator in order to compensate a pricing model.

Furthermore, the chosen model structure with level variables representing the stock of persons per country for each of the five income classes presupposes initial values of number of persons per income class for the year 1990. The next section describes the analysis of income distribution data availability in EU27+2 countries which constitutes the final step in the choice of the best possible modelling framework.

4.3.2.2 Data Analysis and Availability

The consistency of a model regarding data sources for exogenous variables and calibration data is of particular importance. Ergo, most ASTRA-S sub-models are calibrated based on data taken from the comprehensive Eurostat online database. Only in cases where Eurostat cannot provide data in the required desegregation, other data sources like statistics from national statistics offices or UNIDO (2001), UN (2002), OECD (2003) and Worldbank (2001) are considered. Thus, at first Eurostat data has been analysed in a reviewing process if it could fulfil the needs of the chosen income distribution modelling framework. Due to the characteristics of the Eurostat online database, mainly allocating macro-level data, this database offers only time series data reflecting the development of average yearly net incomes per quintile respectively decile in 13 European countries for the period between 1995 and 2001. Based on information of the German Statistical Office, Eurostat collects and aggregates this data from country-specific micro-censuses. Thus, detailed results from different surveys are produced in a non-harmonised way for single European countries.

The LUXEMBOURG INCOME STUDY (LIS) MICRO DATABASE (2008) is a cross-national data archive provided by a non-profit organisation to scientists. The organisation located in Luxembourg collects, harmonises and standardises micro-level income and demographic data from national micro-census since 1983. Today, the data archive covers datasets from 30 countries worldwide and 23 of the covered EU27+2 countries in ASTRA-S (see Table 4-2).

Table 4-2: Overview of Available LIS Income Surveys

Country	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
AUT						X	X		X			X				
BEL				X			X		X			X				
DNK				X			X					X				X
ESP		X					X					X				
FIN			X				X					X				X
FRA	X					X						X				
GBR			X			X	X				X					
GER	X					X						X				
GRC							X					X				
IRL						X	X	X				X				
ITA	X		X		X		X			X		X				
LUX			X			X			X			X				
NLD			X			X					X					
SWE				X			X					X				
CHE				X								X		X		
CZE				X				X								
EST												X				
HUN			X			X					X					
NOR			X				X					X				
POL				X			X				X					
ROM							X		X							
SLO									X		X					
SVK				X				X								

Registered users are allowed to access the database indirectly via email-submission of SAS, SPSS or STATA programs. In a laborious process more than 170 emails with SPSS-coded programs are prepared and submitted to the organisation for each available income type, each available survey year and each of the covered countries. The objective of these emails is to assign the number of survey participants to the determined country-specific income ranges for each income type covered in the survey. *Figure 4-11* represents the code for an example query for the numbers of employed persons within eight net income groups for the Austrian survey of the year 2000. The integrated income steps of the income classes for Austria are not equal with the presented income steps in the previous chapter (485 Euro vs. 533 Euro) as the income values need to be expressed in real terms and, thus, in constant Euro 1995.

Query Code

```
* user = ****
* password = ****
* package = spss
* project = lis
get file = at00p
/keep = pweight pnwage pgwage .
compute factor =   0.072672834 .
compute pnweur = (pnwage * factor) / 12 .
compute cntpgw = 0.
if pnweur gt 0 and pnweur le 485 cntpgw = 1.
if pnweur gt 485 and pnweur le 969 cntpgw = 2.
if pnweur gt 969 and pnweur le 1454 cntpgw = 3.
if pnweur gt 1454 and pnweur le 1939 cntpgw = 4.
if pnweur gt 1939 and pnweur le 2424 cntpgw = 5.
if pnweur gt 2424 and pnweur le 2908 cntpgw = 6.
if pnweur gt 2908 and pnweur le 3393 cntpgw = 7.
if pnweur gt 3393 cntpgw = 8.
frequencies variables = cntpgw.
```

Query Results

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.0000	4258	62.2	62.2	62.2
	1.0000	371	5.4	5.4	67.6
	2.0000	521	7.6	7.6	75.2
	3.0000	781	11.4	11.4	86.6
	4.0000	513	7.5	7.5	94.1
	5.0000	226	3.3	3.3	97.4
	6.0000	89	1.3	1.3	98.7
	7.0000	43	.6	.6	99.4
	8.0000	43	.6	.6	100.0
	Total	6845	100.0	100.0	

Figure 4-11: Example for SPSS-Coded Query and Result of the LIS Database

The single surveys ask the survey participants for different types of yearly income. As most available surveys have been conducted prior to the introduction of the Euro, income values of nearly all surveys are expressed in national currencies such that the average exchange rate of the specific year plus the specific GDP-deflator has to be considered in order to generate constant Euro 1995 values. Furthermore, yearly incomes are transformed into monthly incomes in the submitted programs. The complexity of this process increases as employed and self-employment incomes have been asked heterogeneously in net or gross terms. Half of the countries perform their surveys in net terms, while the other half ask for gross incomes. As the objective of the income distribution model is the simulation of dynamics of net income distribution, the income steps of queries of surveys with gross income are transformed into gross income steps such that they match to the original net income steps. The gross values of income bounds between the income classes are computed under consideration of three different taxation systems: progressive, flat and step-wise taxation.

Table 4-3: Estimation of Upper Bounds per Income Group for Extraction of LIS Database

Country	Gross/Net Income	Upper Bounds of Income Groups in Current Euro			
		Low	Low-Med	Medium	Med-High
AUT	net	533	1,065	1,598	2,131
BLX	net	494	987	1,481	1,974
DNK	gross	1,274	2,791	4,628	6,898
ESP	net	444	888	1,332	1,776
FIN	gross	636	1,326	2,077	2,897
FRA	net	487	973	1,460	1,946
GBR	gross	738	1,475	2,213	2,951
GER	gross	583	1,198	1,846	2,532
GRC	net	389	779	1,168	1,558
IRL	net	548	1,095	1,643	2,190
ITA	net	477	954	1,432	1,909
NLD	gross	862	1,724	2,928	3,904
SWE	gross	594	1,188	1,783	4,802
CHE	gross	554	1,121	1,701	2,296
CZE	gross	410	819	1,229	1,639
EST	net	341	683	1,024	1,365
HUN	net	412	823	1,235	1,647
NOR	gross	1,200	2,399	3,599	4,799
POL	net	375	751	1,126	1,502
ROM	gross	373	746	1,120	1,493
SLO	net	390	781	1,171	1,562
SVK	gross	435	871	1,306	1,742
LUX	net	452	904	1,356	1,808

Apart from gross wages and self-employment income, child-related benefits, unemployment benefits and pensions are queried from the LIS database as well. After finalising the query submission of all required surveys via email, the replies are collected and transformed into a database. The optimal model framework constitutes of only five income groups, all persons originally allocated to the four highest income groups are assigned to the fifth and highest income group.

The next step is the extrapolation of numbers of persons per income group in order to transfer the sample results to the whole population of a country. Therefore, the numbers of six different population segments are taken from EUROSTAT (2008a):

- children younger than 18 years,
- inactive persons between 18 and 65 years,
- employed persons between 18 and 65 years,
- self-employed persons between 18 and 65 years,
- unemployed persons between 18 and 65 years and
- retired persons older than 65 years.

According to the assumption that most children do not have an own income until they reach the age of 18, children are considered to belong to the lowest income group in each modelled country. Inactive persons between 19 and 65 years receive no wages or salaries and, thus, are added to the lowest income group as well. According to the total expenditure of the state for unemployment benefits and the number of unemployed an average benefit per unemployed could be estimated. Under the assumption that unemployment benefits are distributed among all unemployed persons like income of employed persons via a right-skewed frequency distribution (see 4.3.1.2) with the computed arithmetic mean value, all unemployed persons are distributed to the respective income groups according to estimated probabilities. Finally, employed, self-employed and retired persons are allocated to the five income groups due to the observed share in the surveys. As the System Dynamics model requires on the one hand the initial income distribution in the year 1990 and on the other hand complete time series for the calibration of a whole period, data of the missing years have to be estimated in an adequate way.

In all cases in which an income distribution from a survey older than 1990 exists a linear interpolation of the number of persons per income group is assumed. As no former surveys are available for some countries, the initial person numbers per income group are estimated based on the development of the Gini-Coefficient. According to existing significant differences in the sample size of surveys of one country from one year to the next year, a revision of the estimated development via linear interpolation has to be carried out. High growth rates are smoothed as a result of expert judgment in this case. Finally, the assessed income distribution in between two survey years is modified and harmonised with the number of persons in the considered population segments.

In the end, time series for 19 respectively 18[16] countries could be derived from LIS database, as for Estonia, Poland, Romania and Slovakia only insufficient data on the distribution of income has been available. Regarding the sample size of the remaining various available queries within these 19 European countries, the number of participating persons differs between 2,000 and nearly 100,000 persons. The average sample size of 14,300 persons guarantees a high degree of reliability of the basic survey results.

4.3.2.3 Identification and Modelling of Impacts on Income Mobility

After the confirmation of feasibility of the identified optimal modelling framework, all available drivers of income mobility which determine the distribution of income in a country are considered and analysed. In other words, all imaginable and available factors which might cause a change of income of individuals from one income group to another have to be found and classified according to their significance. Therefore, findings of the presented explanatory approaches and theories of income distribution in section 4.3.1 provide an excellent foundation. With regard to the main objective of this thesis, the assessment of income distribution impacts on passenger transport, and the wish to implement models into ASTRA-S that are able to close feedback loops, the ideal income distribution model would manage on endogenous drivers only. As described in paragraph 3, the former version of the ASTRA model was already able to simulate various important socio-economic indicators like GDP, final demand, employment, gross value-added or the demographic structure. Additionally, the implemented distribution of population into household types provides a further valuable input for the income distribution model. Nevertheless, the ASTRA-S model is at least in the socio-

[16] According to the spatial differentiation in ASTRA, described in chapter 3.2.10.2, Belgium and Luxembourg were implemented as one country zone.

economic part still a macro-level model and, therefore, not an adequate instrument to project trends of micro- or meso-level indicators like the development of personal skills and education choice. Hence, the main challenge in this stage is to determine a sophisticated mixture of endogenous and exogenous impact variables on a macro- or meso-level. Several conceivable drivers of income mobility are brought together under consideration of the described explanatory approaches and classified according to their utility for the ASTRA-S income distribution model. The following paragraph depicts this process, demonstrates the reasons for the choice of a certain driver and describes the implementation of the impacts into the income distribution model.

Regarding the existing income distribution models, choice models, for example the model of TINBERGEN (1956), can be considered as most popular. Based on supply and demand balance of work places with certain job specification all employed persons can be assigned to income groups. Derived from this characteristic, the model requires detailed micro-level information of the supply of employees with different personal skill portfolios and skill requirements of all existing work places. On the one hand, ASTRA-S as a macro-level model is not able to provide the necessary information and, on the other hand, exogenous data from socio-economic surveys is not available in the needed detail for all EU27+2 countries. Most explanatory approaches, like choice, sorting or human capital models, appraise personal skills and capabilities as a significant influence of the income distribution and mobility. Even if the basic ASTRA-S model is currently not able to simulate the development of human capital with its skills and education, the factor education respectively highest level of education reached has to be considered as an exogenous driver of income mobility. Therefore, time series for the number of alumni reaching predefined education levels between 1990 and 2005 were taken from EUROSTAT (2008a). The EUROSTAT online database uses the ISCED 1997 (International Standard Classification of Education) classification defined by the UN (2008).

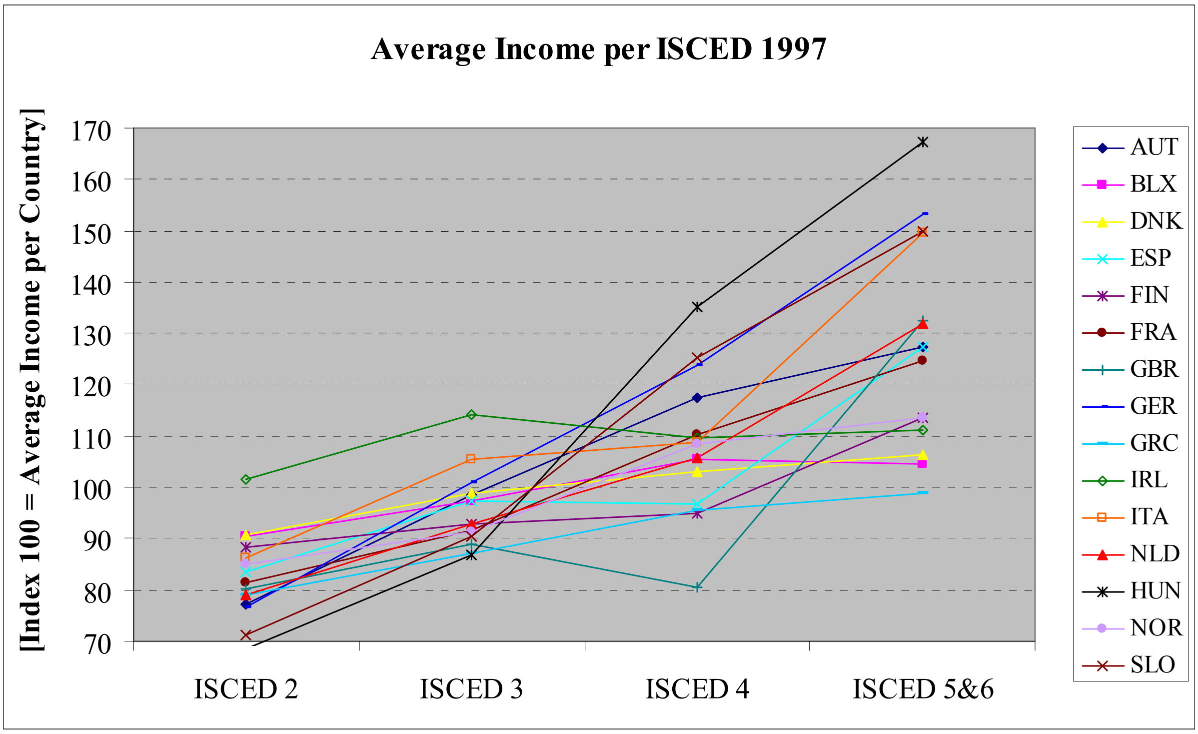

Figure 4-12: Average Initial Income per ISCED 1997 Education Level per Country

Based on EUROSTAT data on average income per highest reached level of education in ISCED 1997 terms, average initial wages for three ISCED levels can be estimated: ISCED 2 (up to lower secondary education), ISCED 3 and 4 (upper and post-secondary non-tertiary education) and ISCED 5 and 6 (tertiary education).

Figure 4-12 illustrates the differences of average initial wages in the year 2002 which supports the consideration of education level as exogenous driver of income distribution. Coherence between education level and average initial income is obvious. In order to integrate this information into the income distribution model, the average age in which the alumni reach the specific level of education is necessary. According to the heterogeneous structure of education in the modelled 18 European countries, average age for each ISCED 1997 level has been calculated based on EUROSTAT data. Average alumni age for the level ISCED 3 and 4 ranges between 17 and 20 while alumni who reached ISCED 5 or 6 levels are on average 22 to 26 years old. The ASTRA-S Population (POP) module provides the numbers of potential alumni which are distributed among final level of ISCED 1997 education. Due to this information and the average initial income, the first cause for income mobility from the lowest income group (Low Inc) to the four higher income groups is considered. The final share of alumni entering a certain income group is predefined with a certain range, based on estimated ranges of initial income around the mean initial income derived from EUROSTAT. The calibration process detects the optimal final share of alumni per ISCED 1997 reaching a certain higher income group or remaining in Low Inc group. The following equation describes the computation of income mobility from Low Inc into all four higher income groups due to transfer from students to workers:

$$IMED_{i,dig} = \sum_{ed} potAL_{i,ed} * shAL_{i,ed} * cIMED_{i,dig,ed} \qquad \textbf{eq. 4-11}$$

where: *IMED* = number of alumni per country *i* that enter destination income group *dig*
potAL = total population that reaches specific alumni age per country *i* and education level *ed*
shAL = share of population in specific age group that reached highest education level *ed*
cIMED = calibration parameter representing the probability for income mobility in *dig*
dig = index for five possible destination income groups
ed = index for three considered ISCED 1997 education levels
i = index for 18 modelled EU27+2 countries

Apart from personal skills reflected on a meso-level via ISCED 1997 education levels, another socio-economic indicator has been detected in the course of the model development: the age structure of the population. BLÜMLE (1975) demonstrates that there is a correlation between the level of income and the age. Figure 4-13 presents the development of average net earned income per person in five age classes: 18 to 29 years, 30 to 39 years, 40 to 49 years, 50 to 59 years and 60 years and older. The depicted figure confirms this correlation visually. According to the illustrated data from EUROSTAT (2008b), all implemented 18 countries possess at least a growth of average income with increasing age until the age of 60. Considering persons older than 60 years, half of the countries are characterised by a slight reduction of income, while the rest shows still increasing average incomes compared to younger workers. Regarding recent trends, observed for example in Germany which indicate declining correlation between age and average income, the continuation of the depicted status from 2002 in the future is at least in its clearness questionable. As this trend is only visible in some of the 18 countries, the factor age can be considered as an important prospective driver of income distribution and mobility. Hence, the depicted age-income correlation is adopted in the ASTRA-S income distribution model. Even if a continuous growth of average net income per person is most likely, a step-wise growth of income is implemented in ASTRA-S. Based on the trend of the year 2002, all employed and self-employed persons for all five age classes per country are assigned according to their most probable, basic income group. For example, the highest share of employed persons between 18 and 29 years are allocated in the Low Inc group.

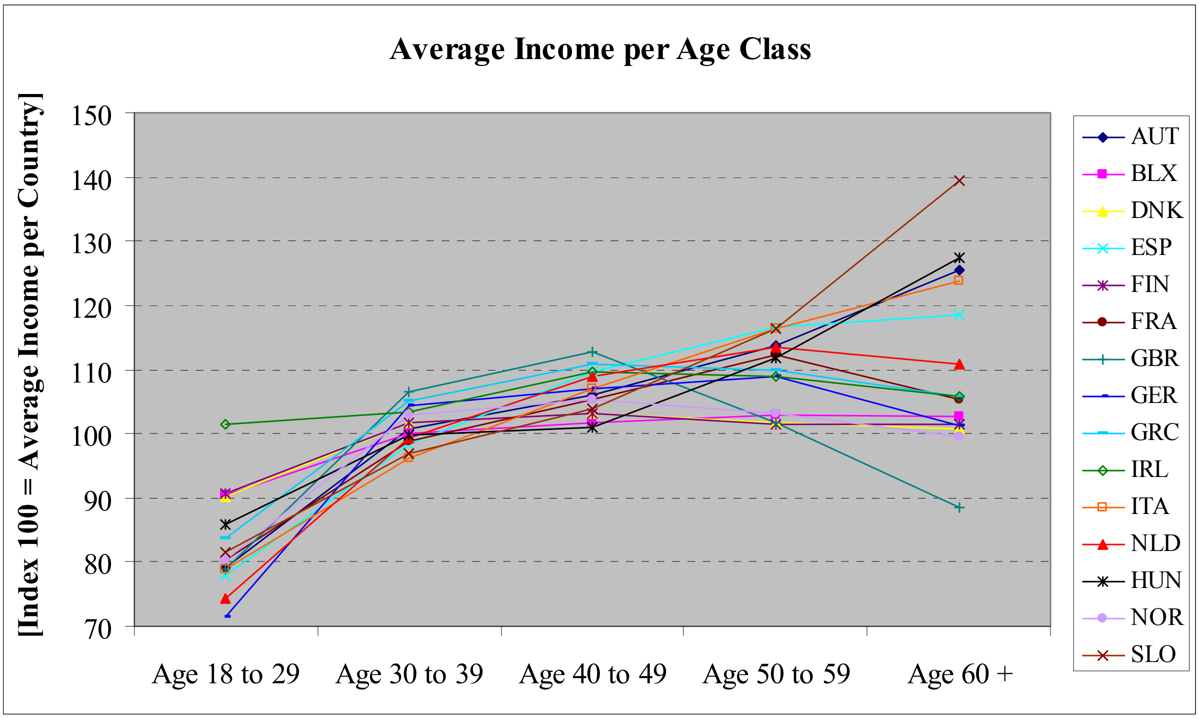

Figure 4-13: Average Income per Age Class per Country

In a second step, the average net income distances per person are computed out of the described age-specific average net incomes and assumed prospective income trends for the five age classes. The probability that an employed or self-employed person of a certain income group moves to a higher or a lower income group is estimated in the final step. Therefore, average net income distances to higher and lower income groups are calculated based on the assumption that persons respectively their incomes are equally-distributed within the five income groups and the assessed net income bounds of the five income groups (see Table 4-3).

The following equation describes the estimation of income mobility due to ageing of employed and self-employed persons into the higher income group (if income increases from one age class to another) respectively the lower income group (if income decreases from one age class to the following):

$$IMAE_{i,ig} = \sum_{ab} \left[\frac{(nY_{i,ab+1} - nY_{i,ab})}{disIG_{i,ig}} * EMP_{i,ig,ab} \right] * cIMAE_{i.ig} \qquad \textbf{eq. 4-12}$$

where: *IMAE* = employed per country *i* that move to lower/higher income group *ig-1/ig+1*
nY = average net income per country *i* and age class under age bound *ab*
disIG = average monetary distance to lower/higher income group
EMP = employed/self-employed persons per country *i*, income group *ig* and age bound *ab*
cIMAE = calibration parameter representing the probability for income mobility due to ageing
ig = index for five possible original income groups
ab = index for age bounds of the five age classes
i = index for 18 modelled EU27+2 countries

Apart from the ageing of employed persons between 18 and 65 years, the age in which employed persons retire constitutes another incident which induces income changes. Retired persons do not get anymore salaries from their employer but pensions from the state or private insurances. According to net replacement rates at average earnings (see Table 4-4) per income class and country derived from OECD (2005) the former wages can be transformed into pensions.

Table 4-4: Net Replacement Rates at Average Earnings

Country	Level of Net Income Before Retirement Compared with Average					
	50%	75%	100%	150%	200%	250%
AUT	91.2%	93.4%	93.2%	93.5%	79.3%	63.2%
BLX	82.7%	63.8%	63.1%	53.3%	42.7%	36.0%
DNK	95.6%	68.0%	54.1%	42.5%	35.5%	30.8%
ESP	88.7%	89.4%	88.3%	88.4%	83.4%	68.8%
FIN	90.7%	78.8%	78.8%	79.2%	78.3%	79.3%
FRA	98.0%	70.8%	68.8%	62.6%	59.2%	57.0%
GBR	78.4%	57.7%	47.6%	38.2%	29.8%	24.7%
GER	61.7%	66.6%	71.8%	79.2%	67.0%	54.2%
GRC	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%
IRL	63.0%	47.0%	36.6%	27.4%	21.9%	18.3%
ITA	89.3%	88.0%	88.8%	88.4%	89.1%	89.0%
NLD	82.5%	88.2%	84.1%	85.8%	83.8%	82.8%
SWE	90.2%	76.4%	68.2%	70.1%	74.3%	75.0%
CHE	71.4%	68.9%	67.3%	53.0%	41.4%	34.3%
CZE	88.3%	68.3%	58.2%	42.9%	35.3%	31.0%
HUN	86.6%	90.9%	90.5%	99.1%	92.6%	81.8%
NOR	85.5%	73.1%	65.1%	58.2%	50.1%	42.8%
SLO	84.1%	73.2%	68.7%	64.3%	59.4%	54.5%

Source: OECD (2005)

As the income distribution model does not differentiate explicitly persons within an income group into age cohorts, at first, all employed persons which reach the age of 65 have to be assigned to the five income groups. Under consideration of the correlation between wage and age, it is obvious that the current share of all employed persons per income group cannot be taken for 65-year-old persons. The development of average income per country is offset against the basic share of all employed persons in each income group. The resulting share indicates a more realistic distribution of 65-year-old persons on the five income groups. The second step in the simulation of income mobility caused by transfer from wages to pensions is the determination of the probability that a pensioner declines no, one, two or even three income groups compared to the former situation as an employed. Retired persons in Denmark, UK, Ireland and Czech Republic that belong to the highest income group (High Inc) have to compensate the highest decline in income by three income groups. Assuming that employed persons who reach the age of 65 are distributed equally within the income group, probabilities that the new pension leads to a decline by one, two or even three income groups can be estimated with the help of net replacement rates at average earnings. Similar to the implementation of ageing and education impacts on income mobility, the final number of persons declining from an income group to another is calculated under consideration of elements of uncertainty such as the existence and dimension of additional private pensions. Thus, the resulting probabilities include a calibration parameter which is able to vary the original probabilities in order to meet the statistical development of persons per income group between 1990 and 2004. Regarding the development of pensions and ageing societies in many European countries that are characterised by increasing ratios of retired persons compared with labour force, a trend factor considering the drop of pensions is included as well. The government model within the ASTRA-S MAC module computed average pensions based on the revenues, expenditures and government policy.

$$IMRET_{i,ig-n}(t) = shRET_{i,ig} * RET_i(t) * decIG_{i,ig-n} * cIMRET_{i.ig} * trPEN_i(t) \qquad \textbf{eq. 4-13}$$

where: *IMRET* = new retired persons per country *i* that move from *ig* to lower income group *ig-n*
shRET = share retired persons per country *i* and basic income group *ig*
decIG = probability that a new retired person declines by *n* income groups in country *i*
RET = number of persons that reach the age of 65 per country *i*
cIMRET = calibration parameter representing the uncertainty of pensions at retirement
trPEN = factor representing the development of pensions per country *i*
ig = index for five possible original income groups
n = index for possible decline of income group (n= 0,…,4)
i = index for 18 modelled EU27+2 countries

The application of outputs from the income distribution model for the purpose of mobility analysis requires that the income distribution model covers the whole population, not only employed or retired persons. Therefore, also children have to be considered. The ASTRA-S POP module provides the number of births per time step which enter the Low Inc group, even if at least young children do not have an own income. At the opposite, also deaths have to be extracted from the level variables representing the number of persons per income group. In contrast to births the implementation is more complex. Actually, detailed information about the income status of people in different age classes plus the age-specific death rates would be necessary for distributing deaths among income groups. As at least the needed micro-level data was not available, the share of deaths per income group is derived from the total share of persons per income group. This information allows the determination of outflows caused by death of all five income groups.

The loss of a job or a new engagement finishing a period of unemployment represents a further incidence that might induce changes of income distribution. The employment model of the MAC module simulates the dynamics of the EU27+2 labour markets. Besides full-time, part-time and full-time-equivalent employment per sector the number of unemployed is one of the main outputs of this model. The change of unemployment respectively the number of new unemployed or the number of new employed constitutes the major input for the modelling of income mobility in this context. As opposed to the impact of retirement, the model assumes that income difference due to unemployment compensations is stronger limited such that new unemployed persons are only moving by a certain probability to the first lower income group. Unemployment can occur in every income group, even well-paid employees in the High Inc group might become unemployed. Therefore, an equal distribution of new unemployed persons among income groups is presumed. The resulting share can be varied in the calibration process such that the final distribution to income groups and, hence, the probability for a decline of one income group might differ. The following equation depicts the described coherence and the computation of income mobility to a lower respectively higher income group caused by new unemployment respectively new employment.

$$IMUE_{i,ig}(t) = (unEMP_i(t) - unEMP_i(t-1)) * cIMUE_{i.ig} * trUEC_i(t) \qquad \textbf{eq. 4-14}$$

where: *IMUE* = new unemployed/employed persons per country *i* that move from *ig* to lower/higher income group *ig-1/ig+1*
unEMP = unemployed persons per country *i*
cIMUE = calibration parameter representing the distribution of unemployed per income group *ig*
trUEC = factor representing the development of unemployment compensation per country *i*
ig = index for five possible original income groups
i = index for 18 modelled EU27+2 countries

The explanatory approaches by KUZNETS (1965) or HARRISON/BLUESTONE (1988) presented in section 4.3.1.5 consider structural transfers of employment from primary to secondary respectively secondary to tertiary as main driver of income inequality. Despite the fact that at least Simon Kuznets hypothesis could not be confirmed in the US after 1960, wage differences between economic sectors can be significant during periods of structural changes in economies. One of the most important parts in the MAC module of ASTRA-S is the sectoral interchange model. It simulates the sectoral interweavement and the changes of sectoral structures in economies. Moreover, it is mainly responsible for sectoral changes on EU27+2 labour markets. The number of full-time and part-time employed persons per sector in each country can be derived from the employment model. Together with the difference of average wages observed in the past by statistics like EUROSTAT (2008a) it provides valuable information to the income distribution model.

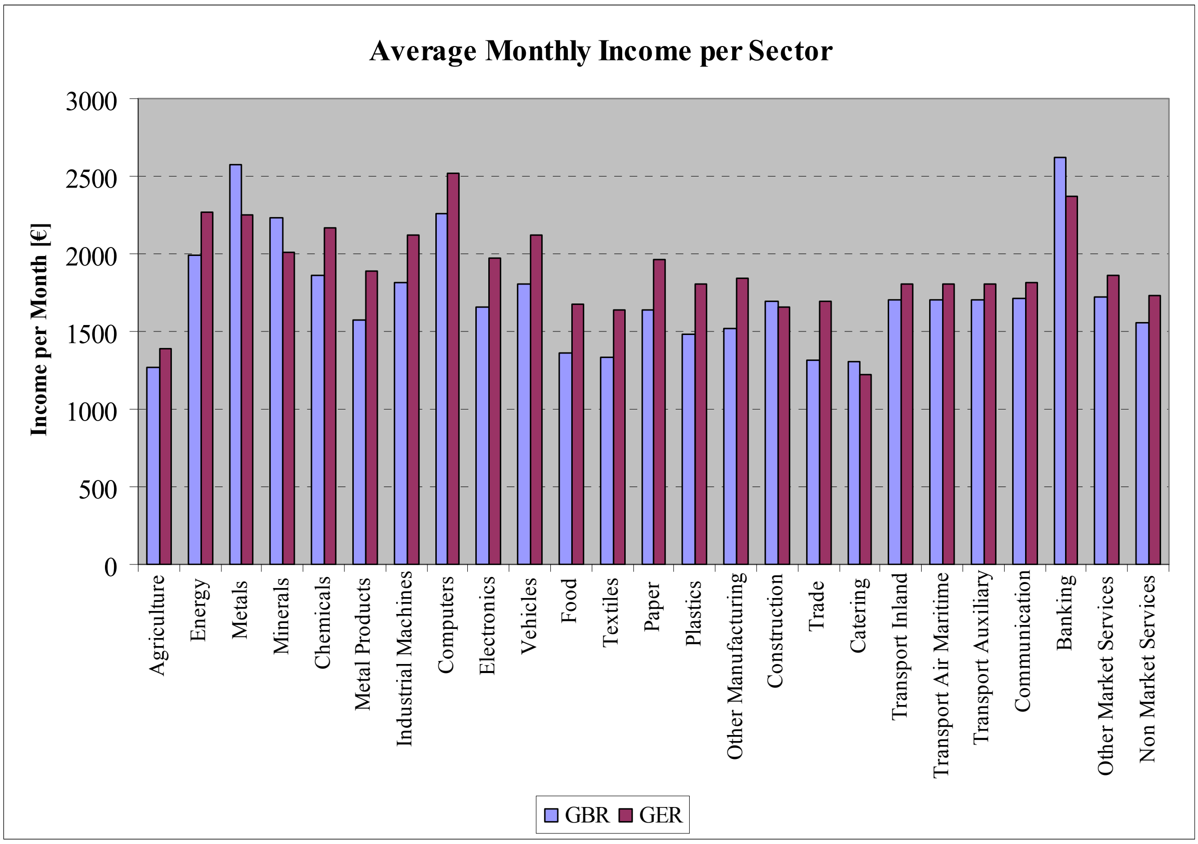

Figure 4-14: Average Income per Person per Economic Sector for Germany and UK

Figure 4-14 demonstrates the differences of average wages between the 25 economic sectors covered in ASTRA-S taken from EUROSTAT for the year 2002. The primary sector represented by Agriculture and the Catering sector have the lowest average incomes per month, while especially the Banking, Computers and Metals sector are outperforming.

Based on this empirical data and the number of employed persons per sector, the model estimates the total income generated by all employees and self-employed persons of all sectors. Total monthly income changes due to structural changes of the labour market and income trends that are implemented as exogenous factor determining the prospective development of income per sector. The income distribution model assumes that the difference between total income of period *t* and the previous period *t-1* determines the number of persons that move to a lower or higher income group. Ergo, the model divides total income difference per country by the average distance to the next higher (if income increases) or next lower income group (if income decreases). The resulting number represents the potential number of persons that move to a lower respectively higher income group induced by sectoral employment changes. Similar to the approaches applied for the distribution of potential income mobility to an original income group, the potential persons moving to other income groups are distributed to their origin income group according to a calibration parameter. The following equation points out this approach:

$$IMSE_{i,ig}(t) = \frac{\sum_s \left[nY_{i,s} * trnY_{i,s}(t) * (EMP_{i,s}(t) - EMP_{i,s}(t-1))\right]}{disIG_{i.ig}} * cIMSE_{i.ig} \qquad \textbf{eq. 4-15}$$

where: *IMSE* = new unemployed/employed persons per country *i* that move from *ig* to lower/higher income group *ig-1/ig+1*
nY = average net income per country *i* and sector *s*
disIG = average monetary distance to lower/higher income group per country *i*
EMP = employed/self-employed persons per country *i* and sector *s*
cIMSE = calibration parameter representing the probability for income mobility from income group *ig* to lower/higher income group
ig = index for five possible original income groups
s = index for 25 economic sectors covered in ASTRA-S
i = index for 18 modelled EU27+2 countries

HARRISON/BLUESTONE (1988) detected a correlation between the number of single parent households and income inequality, as single parents have a limited time budget for working and most often do part-time working. Originally, the number of women in the labour market which are working in part-time jobs is identified as a possible impact on income mobility. The consideration of single parent households goes into the same direction such that the original impact was not integrated in the income distribution model. Compared to the share of part-time employed women, the development of single parent household could be endogenised in the established household model. It is integrated in the POP module and provides the trends for single parent households required for the consideration in the income distribution model. Increasing differences in numbers per annum of this household type initiate income mobility in lower income groups. The final probability of the impact on income mobility from a higher to a lower income group is estimated in the calibration process.

$$IMSPH_{i,ig}(t) = (SPH_i(t) - SPH_i(t-1)) * cIMSPH_{i.ig} \qquad \textbf{eq. 4-16}$$

where: *IMSPH* = new single parent households per country *i* that move from *ig* to lower income group *ig-1*
SPH = number of single parent households per country *i*
cIMSPH = calibration parameter representing the probability for income mobility from income group *ig* to lower income group
ig = index for five possible original income groups
i = index for 18 modelled EU27+2 countries

The last effect considered as driver of income distribution is the development of direct taxes and social contributions. Initiated by redistribution policies of governments, changes of direct taxes and contributions directly impact the composition and structure of income distribution. The chosen approach for the integration of impacts of direct tax and social contribution changes is similar to the described approach for the integration of sectoral employment changes. The only difference from this approach is constituted by the fact that social contributions and direct taxes depend on the level of income. Hence, the distribution of effects to persons of different income groups is not linear. Based on income specific taxes in each country, the financial burden is estimated and distributed to the persons in the respective income groups. For this purpose, the average income under consideration of equal distribution of incomes within the five income groups is taken. Similar to the impacts of sectoral employment changes, changes in direct taxes and social contributions generated in the government model of the MAC module might cause for a certain number of employed a decline or an ascent of one income group (see eq. 4-17).

$$IMTAX_{i,ig}(t) = \frac{(TAX_i(t) - TAX_i(t-1)) * EMP_i(t) * shEMP_{i,ig}}{disIG_{i.ig}} * cIMTAX_{i.ig} \quad \textbf{eq. 4-17}$$

where: *IMTAX* = new employed persons per country *i* that move from *ig* to lower/higher income group *ig-1/ig+1* because of taxation changes
TAX = average direct tax and social contribution per person per country *i*
disIG = average monetary distance to lower/higher income group per country *i*
EMP = employed/self-employed persons per country *i*
sh*EMP* = share of direct taxes and social contributions to be paid by income group *ig*
cIMTAX = calibration parameter representing the probability for income mobility from income group *ig* to lower/higher income group caused by taxation changes
ig = index for five possible original income groups
i = index for 18 modelled EU27+2 countries

The final step in the development of the income distribution model is the validation. The optimal values of all implemented calibration parameters are determined in the calibration process where the endogenously simulated number of persons per income group is adjusted to fit the LIS income distribution data. Calibration parameters play a significant role in the modelling process as they reflect existing quantitative uncertainties in the significance of a single indicator for the explanation of income mobility. Principles of the ASTRA-S calibration process are described in chapter 4.7.

Similar to other ASTRA models, the model structure of the income distribution model uses so-called *subscripts* which represent sets of elements like countries or income groups. This feature enables a well arranged design of the model. Due to the lack of data for ten of the EU27+2 countries, all level and flow variables of the income distribution model are modelled using a *subrange* of the subscript that represents a subset of the country subscript “EUCoun” which is called “EUCoun_INC”. In case that at a later date income distribution data is available for the remaining ten EU27+2 countries, the model structure does not have to be changed. Replacing the subrange “EUCoun_INC” by the complete subscript would be the simple way to update the model. Appending single countries to the model is even simpler, as only the new country has to be added to list which defines the elements covered by the subrange “EUCoun_INC”.

The main output of the income distribution model is the allocation of persons into income groups with fixed monthly net income. Due to the complexity of the model and the number of impacts considered, the model is not able to estimate the development of the distribution of incomes within the income groups. As this information is not required for the main purpose of this thesis - the analysis of passenger trip generation - this lack is not severe. Nevertheless, the internal distribution of incomes within the five income groups could be used as input for a sophisticated modelling of passenger car registrations. Originally, the main drivers of passenger car registration respectively motorisation are the development of average income per adult expressed in real terms, the demographic development and the fuel price trends. Chapter 4.5.2 clarifies the value-added of this information which would improve the quality of this model and its results.

4.4 Passenger Transport Model

This section begins with an introduction to the theory of passenger trip generation as the first stage of the classical four-stage-transport model. After this overview of the underlying theory, the available travel surveys are analysed resulting in the determination of the most significant personal characteristics concerning the mobility pattern. In this context, the applied variance analysis approach is presented. The chapter concludes with a description of the method that is chosen for the calculation and adjustment of passenger trip rates.

4.4.1 Trip Generation Approach

The main objective of this section is the description of the theoretical background of passenger trip generation approaches. Furthermore it should introduce the specific expressions and the applied econometric approaches and support the understanding of the model structure. Chapter 3.2.4 and 3.2.5 already provided an outline of the main characteristics of the four-stage transport model approach applied in the ASTRA model. This chapter should give a more detailed insight into the theory of the first stage, the trip generation.

In order to support the understanding of the described trip generation approaches and the choice of an appropriate model structure, the term *trip* should be clarified first. A trip can be defined as directed movement of a person from an origin to a destination. Trips can be made with every imaginable and available transport mode, such that trips include walking as well as motorised trips by car or train. Usually, trips can be distinguished into two main categories: *home-based trips* (HB) and *non-home-based trips* (NHB). The first is described as a trip that either starts or ends at the home of a person. The second category of trips covers all trips that neither start nor end at home. A trip from the workplace to a shopping centre could be an example for a NHB trip. The passenger trip generation model implemented in the ex-ante ASTRA model is not able to simulate NHB trips. As only HB trips can be simulated, the remaining NHB trips were adjusted to HB trips. Hence, the depicted NHB trip from workplace to shopping centre would be transformed to a HB trip for the purpose of shopping. HB trips can be distinguished according to the purpose of the trip respectively the activity at the destination zone which is called *trip purpose*. ORTÚZAR/WILLUMSEN (1990) differentiate between five trip purposes: business, education, shopping, leisure and other trips. The ex-ante ASTRA model covers in total three trip purposes: business, private and tourism. The trip purpose business consists of business and education trips, private ones cover shopping and leisure trips and tourism represents other trips.

The main objective of a passenger trip generation model as part of the classical four-stage model is the estimation of the number of trips done by a person, starting and ending in all covered geographical or functional zones. Thus, the classical trip generation approach which has been applied in state-of-the-art transport models for more than 40 years (ORTÚZAR/WILLUMSEN 1990) can be differentiated into the following two sub-models:

- A *trip production* model which generates the number of trips that have their origin in a certain zone of a geographical area and
- a *trip attraction* model which estimates the number of trips that have their destination in a certain zone of a geographical area.

Generally, trip production and attraction models can be allocated into three different categories of approaches:

- *Zonal-based* approaches cover aggregated, zonal-based models that estimate the number of trips, based on the number of inhabitants, employees and other socio-economic indicators of a zone.
- *Household-based* approaches consider disaggregated models on household level that assume invariant mobility patterns of specific household classes.
- *Person-based* approaches are similar to the latter household-based approaches and consider the same kind of models for specific person classes.

In the 1960s, trip generation models usually applied regression analysis in order to compute the number of trips per zone. The applied methods varied from linear regression over multiple to non-linear regression analysis. In the late 1960s, the so-called *Category Analysis* emerged in the UK which is nearly identical to the method called *Cross Classification* developed in the US. These methods were applied mainly in regional transport studies in the US and replaced the regression analysis. The basic idea behind this method is the classification of people or households living in a zone according to socio-economic attributes into specific classes. This method presumes that individuals or households with similar composition of attributes show similar mobility patterns or, in other words, that mobility behaviour correlates with socio-economic attributes. The presumed coherence of these first Cross Classification models between attributes and mobility behaviour can be regarded as a simplification. In reality, a second causal coherence exists which focuses on the activity at the trip destination respectively the purpose of the trip. Thus, the desire or necessity to participate in an activity induced by socio-economic attributes causes a trip.

Finally, the total number of trips originating in a zone is computed via multiplication of *trip rates* per person or household category and the number of individuals or households per category in the respective zone. Trip rates are defined as average number of trips of a person or a household within socio-economic attribute clusters per time period. The time period can comprise a single day, a week, a month or a whole year. Trip rates can be estimated based on analysis of mobility surveys which is carried out in the following chapters. The number of individuals or households per attribute cluster for each zone is in most models derived from micro-censuses or from socio-economic panels.

The independence in the determination of zones per country is one of the major benefits of the Cross Classification approach. This approach enables the definition of a spatial zoning system with different sizes of zones or even the aggregation of discontinuous geographical zones to functional zones as it has been done in ASTRA. Chapter 3.2.10.2 describes the determination of spatial differentiation for ASTRA. As opposed to regression analysis which requires predefined assumptions on the functional relations between attributes, Cross Classification does not need such assumptions. Thus, functional relations between single classes of trip rates can be different. Emerging non-linearities can be covered with Cross Classification. The lack of an adequate, statistical test procedure which might measure the quality of the trip generation model constitutes a weakness of this approach. The only method to measure the quality is via comparison of data on aggregated level. Dependency between two or more attributes which can not be avoided in reality represents another weakness, as the reciprocal dependency can lead to estimation errors. Furthermore, the required sample size experiences a non-linear increase with the number of attributes considered. According to ORTÚZAR/WILLUMSEN (1990), mobility surveys should be filled with at least 50 observations per attribute cluster.

The former ASTRA model partially differs in the trip generation and the following trip distribution approach from the classical four-stage model. The classical modelling method has been adjusted because of one major characteristic of the ASTRA model: the ASTRA model is a dynamic model that produces results from the initial year 1990 until the final simulation year 2040 for every quarter year. In contrast, classical transport models are often static models that estimate the transport performance for a base year and a prospective simulation year. Therefore, a significant difference between the number of calculations exists: the ASTRA model would compute results for more than 200 time steps, while the static models calculate only twice. Usually, this characteristic of ASTRA does not cause unsolvable problems. Only the suggested application of gravity functions in the trip distribution stage which carries out the simulation of destination choice resulting in origin-destination matrices initiates an overstraining of computational resources. Resulting matrices have to be adjusted at each time step in order to balance the resulting sums of rows and columns representing the number of produced and attracted trips. The adjustment of the gravity function is performed with the so-called FURNESS (1965) iteration approach. Actually, the sequence of calculations caused by this approach would cause a computational break-down during an ASTRA simulation. Therefore, an alternative was derived by SCHADE (2005) from the classical approach which avoided the application of a gravity function in the following trip distribution stage. The alternative trip distribution approach which is implemented in ASTRA and described in chapter 3.2.4.3 substitutes the gravity function by a logit function. The aim of the logit function is the computation of probabilities of potential destination zones for all trips starting in a certain zone. Impedance matrices, containing information about the average time and costs required for a trip from origin zone *O* to destination zone *D*, provide the major input for the estimation of probabilities. As the destination choice is performed via logit function which requires no adjustment, the trip attraction matrices are redundant. Hence, the trip generation model in ASTRA and ASTRA-S consists of a trip production model only. Nevertheless, the model is described in the following as trip generation model and not as trip production model.

The MAC, POP and VFT modules of ASTRA enable endogenous calculation of significant socio-economic indicators. Based on the outputs, the population can be differentiated into population segments with characteristic mobility behaviour. Those population segments can be composed of multi-dimensional attributes, like car-ownership, employment status, age cohort, etc. Thus, the person-based Cross Classification method which has already been applied in the ex-ante ASTRA version remains the most comprehensive approach also for the ASTRA-S trip generation model.

The following general equation shows the implemented trip generation approach. The identification of the attribute clusters of individuals is presented in the following chapters. The definition of the three trip purposes is adapted from the former ASTRA model version. The determination of spatial differentiation for ASTRA is described in chapter 3.2.10.2. The chosen spatial differentiation was sufficient for the purpose of this thesis, the assessment of income distribution impacts on mobility. Nevertheless, a more detailed population model is developed in order to increase the quality of the trip generation process by simulating the development of population per age cohort in each NUTS2[17] zone of the covered EU27+2 countries. Unfortunately, the computational constraints do not allow a continuation of the differentiation into trips per NUTS2 zone in the following stages of the implemented transport model. The resulting growth of level of trip matrices would lead to a break-down of ASTRA during the simulation. Regarding the application of the ASTRA model together with a specified transport model like VACLAV (SCHOCH 2004), the trip generation with differentiation into NUTS2 zones can provide a valuable input for the transport network model. The linkage of ASTRA and VACLAV has been applied the first time within the TRIAS project (KRAIL ET AL. 2007). The structure of the NUTS2 population model is similar to the former population model. The only difference remains in the definition of age cohorts. The more detailed NUTS2 model computes the population in one-year-age cohorts whereas the country-level population model simulates the population in quarter-year cohorts.

$$OT_{i,z,tp} = \sum_{ac} \left[POP_{i,z,ac} * TR_{i,tp,ac} \right] \qquad \textbf{eq. 4-18}$$

where: *OT* = total number of trips that start in country *i*, zone *z* for trip purpose *tp*
POP = population per per country *i*, zone *z* and attribute cluster *ac*
TR = trip rate per per country *i*, trip purpose *tp* and attribute cluster *ac*
tp = index for three trip purposes
ac = index for attribute cluster
z = index for functional zones
i = index for 18 modelled EU27+2 countries

4.4.2 Revision of Trip Generation Model

In order to enable the analysis of income distribution impacts on passenger trip generation, the basic trip generation model integrated in the ASTRA REM module has to be modified. The adjustment process is described in this paragraph. At the beginning, available travel surveys are presented. Moreover, the choice of the most adequate survey regarding the objective of this thesis is described. This survey is then analysed and applied to generate the final trip rates. The major challenge consists of the determination of a sophisticated structure for the trip generation model. The optimal structure should be as close to real trip making decisions as possible. Based on existing mobility surveys around Europe, single attributes and attribute clusters of persons are analysed regarding their influence on personal mobility. Considerating the main task of this thesis, the personal income is predefined as one of the attributes, that impact the trip generation. The identification of other attributes according to their explanatory power on mobility of persons having a certain specification of an attribute is carried out with a statistical method called *variance analysis*. In the second sub-chapter, the principles of this method are presented and the choice of final attributes is illustrated. Finally, this chapter concludes with the description of the calculation and adjustment of trip rates.

4.4.2.1 Travel Surveys

The main objective of mobility respectively travel surveys is the identification of stated preferences of persons or households regarding their mobility. Detailed information about mobility patterns of the population is essential for transport policy makers and consumer-

[17] NUTS is the abbreviation of Nomenclature of Territorial Units For Statistics for European regions. NUTS0 is equivalent to the country level, NUTS1 to federal states and NUTS2 to administrative regions.

oriented transport planning. Moreover mobility surveys allow insights into various reasons of certain transport developments. The most important European travel surveys are:

- British National Travel Survey (NTS),
- German Mobility Panel (MOP),
- Mobility in Germany (KONTIV),
- Dutch National Travel Survey (NTS) and the
- Swedish National Travel Survey (RES).

One of the main requirements on a travel survey concerning the application of survey results in the planned trip generation model is an adequate sample size. The British NTS (DFT 2006) is a continuous survey of British mobility behaviour since 1988. In the last survey in the year 2006 about 8,300 households participated. The Mobility in Germany (DIW 2003) survey was carried out 4 times between the years 1976 and 2002. Its sample size in the year 2002 was about 50,000 households. The MOP is a panel by tns infratest and the Institute for Transport (IFV) of the University Karlsruhe (TH). The average sample size of the MOP is about 1,000 households per year, whereas the MOP is carried out every year since 1994. The Swedish RES of the year 2005 prepared questionnaires for about 27,000 persons, with a response rate of 68 %. The Swedish survey was commissioned every year since 1994.

Another, possibly more important requirement on the survey is the content. For example, the Dutch NTS does not provide information about trip making of persons and households with required attributes. Hence, it can not be used for the purpose of this thesis. Finally, only three travel surveys remain fulfilling the requirements on the questionnaire. The first one is the British NTS which considers the income of individuals as an important driver of mobility. Figure 4-15 presents an extract of the British NTS which demonstrates the average yearly trips per person for each income quintile in the year 2006. The difference in total number of trips per person between the lowest and the highest income quintile is nearly 25 % which indicates the significance of income already on the first stage of classical transport modelling. The second remaining travel survey is Mobility in Germany carried out by DIW which queried the number of trips per person or households for fixed income classes. The last travel survey meeting the requirements of this thesis is the German Mobility Panel (MOP). Similar to the previous study the MOP queries every trip made by households and members of the household which are differentiated by fixed income classes. Since the year 2002, panel members which participated in the MOP are requested to declare their household income in terms of an assignment to eight fixed monthly household income groups. Members are asked to denote every single trip made within one exemplary week.

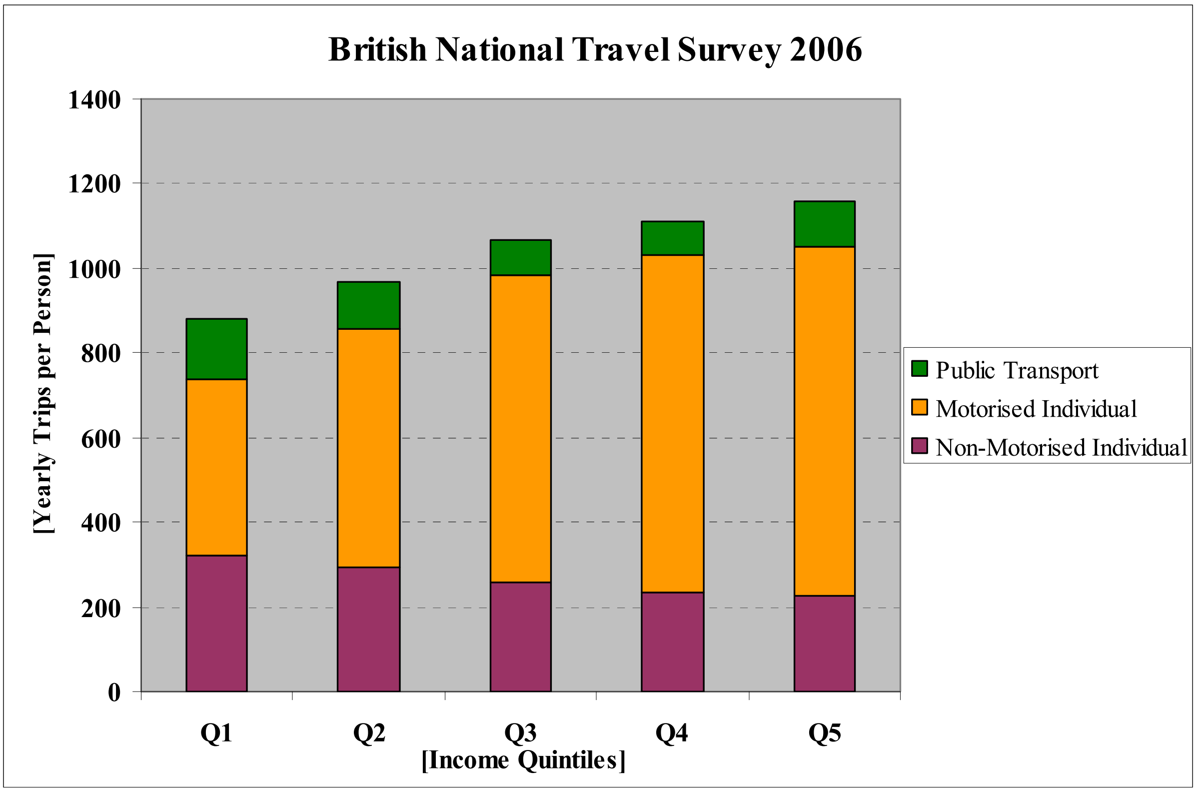

Figure 4-15: Average Yearly Trips per Person for each Income Quintile in the UK 2006

The findings of the British NTS could not be used for this thesis, as the panel members were assigned to income quintiles and not fixed, absolute income classes. As described in chapter 4.3.2.1 the resulting numbers could not be transferred for trip generation in all other modelled European countries. Actually, Mobility in Germany provided with a huge sample size and the required differentiation of persons and households into fixed income groups an optimal travel survey for the analysis of mobility patterns in this thesis. Unfortunately, the structure of the available database does not allow the combination of two or even more attributes for building person clusters. The identification of trip rates would have required several assumptions which would not be the desired accurate solution. Therefore, the German Mobility Panel was chosen as the best available travel survey for the analysis in this thesis. In order to compensate the smaller sample size and due to the fact that most panel members did not participate over all covered years, the documented trips between 2002 and 2006 were considered. Hence, more than 168,000 trips documented by 3,890 households consisting of 6,889 persons are available for the following analysis.

Besides the number, length, duration and transport mode of a trip, the MOP requested several socio-economic attributes of participating persons respectively households. As mentioned in paragraph 4.3.2.1, each household has to state the monthly net household income. For data protection reasons the incomes are assigned to eight income classes in the MOP database each with a range of 500 Euro. Furthermore, households are distinguished by the number of persons and children per household and by four household types. These household types are not equivalent to those types that are differentiated in the ASTRA-S household model.

The most significant differentiation of individuals can be made by:

- four employment situations (full-time employed, part-time employed, unemployed and inactive),
- eight age classes (younger than 18 years, 18 to 25 years, 26 to 35 years, 36 to 50 years, 51 to 59 years, 60 to 69 years and 70 years and older),
- three car availabilities (owner of car, shared car, no car) and
- five education levels.

In the following chapter the attributes are sorted based on their explanatory power regarding mobility. For the determination of further representative attributes besides personal income, an analysis of variance for the most significant attributes is carried out and described in the next chapter.

4.4.2.2 Determination of Population Segments

There are 18 countries which could be integrated in the income distribution model. Before their modelled population is assigned to specific clusters of persons with certain combination of socio-economic attributes, the most significant attributes have to be identified. Considering the main objective of this thesis, the attribute income per income class is determined as first and most important attribute. This constitutes a prerequisite, as otherwise the impact of income distribution could not be assessed with the ASTRA-S model. In the following the chosen approach for and the results of the determination of one or more further attributes are described. This chapter concludes in presenting the simulation of development of the population within each attribute cluster.

The *analysis of variance* (ANOVA) was mainly developed by Fisher in the 1920s. It represents a statistical method of analysis to explore the effect of one or more dependent (exogenous) variables on one independent (endogenous) variable (see eq. 4-19). The variance analysis answers the question if the different states of one factor show statistical significant different effects on the concerning attribute and quantifies the effects (HARTUNG ET AL. 1995).

$$Y = f(z_1, z_2, ..., z_n) \qquad \textbf{eq. 4-19}$$

where: Y = dependent (exogenous) variable
z = index for number of specifications per attribute
n = index for number of observations in survey

For independent variables the nominal scale is a minimum requirement. The nominal scale is characterised by describing different states, for instance the separation of gender with the following attributes: male and female. Dependent variables have to be scaled in a metric way (AUER 1999). The aim of application of a variance analysis for trip generation is the accomplishment of an evaluation and consequently the choice of an adequate scheme of classification for persons based on their socio-economic attributes. The chosen socio-economic attributes should map the behaviour in the person classes as close as possible. In this case, “as close as possible“ means that the standard deviation of the distributed trip rates in each person class should be preferably low. So that the single trip rates of persons in a person class vary as little as possible from the mean of the class, in order to guarantee a comprehensive representation of the mobility behaviour of the whole class. The choice of attributes provides the foundation for the creation of the trip rate matrix with the help of Cross Classification method.

In general, the variance analysis is classified by the number of independent variables respectively attributes or factors. In the following, the one-factorial analysis will be presented according to BACKHAUS (1990).

For a better understanding the theoretical explanation is accompanied by an example which is part of the analysis of the MOP. As a possible classification schema, the influence by the age of a person on the produced trips for the ASTRA-S trip purpose "business" is explored. The age of a person as an independent variable contains seven age classes (see previous chapter). Table 4-5 presents more than 3000 trip observations as well as the mean of the number of trips per week for trip purpose business for seven age classes.

Table 4-5: MOP Analysis on Significance of Attribute Age on Trips per Person

Observation *i*	**Age Class *z***						
	0 to 17	**18 to 25**	**26 to 35**	**36 to 50**	**51 to 59**	**60 to 69**	**70 plus**
1	0	0	0	11	0	0	0
2	0	5	0	0	0	0	0
3	0	0	8	0	0	0	0
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
3331	0	0	0	0	8	0	0
Mean p. Class	**$\hat{y}_1 = 6.86$**	**$\hat{y}_2 = 7.73$**	**$\hat{y}_3 = 8.09$**	**$\hat{y}_4 = 8.58$**	**$\hat{y}_5 = 8.07$**	**$\hat{y}_6 = 4.52$**	**$\hat{y}_7 = 2.52$**
Total Mean	**$\hat{y} = 7.66$**						

If there was no influence of the attribute age class on mobility patterns, the projected value for the number of business trips would be reflected by the total mean $\hat{y}$. Considering that there is an influence of the age of persons on the number of trips per week, the forecasted value per age class is $\hat{y}_{1,\ldots,7}$. The deviations between the total mean and the means of the age classes $\hat{y}_z$ are explained by the different attributes of age. The deviation between the means of the classes and the observed values ($\hat{y}_z$ - $\hat{y}$) are reduced on random influences, and therefore not explained. The aim is the minimisation of those unexplained deviations. The total deviation between an observed number of trips and the total mean can be differentiated into two segments: explained and unexplained deviations. In order to analyse the quality of the chosen classification for all observations, the deviations are aggregated as *sum of squares* (SS) of the single deviations according to the following equations:

$$SS_t = \sum_{z=1}^{Z}\sum_{i=1}^{I}(y_{iz} - \overline{y})^2$$ **eq. 4-20**

$$SS_b = \sum_{z=1}^{Z} I\,(\overline{y}_z - \overline{y})^2$$

$$SS_w = \sum_{z=1}^{Z}\sum_{i=1}^{I}(y_{iz} - \overline{y}_z)^2$$

where: SS_t = sum of the squared total deviations
SS_b = sum of the squared deviations between the classes (explained deviation)
SS_w = sum of the squared deviations within the classes (unexplained deviation)
y = observed number of trips per week per person per attribute z in observation i
$\hat{y}_z$ = mean number of observed trips of persons with attribute z
$\hat{y}$ = total mean number of all observed trips
z = index for number of specifications per attribute
i = index for number of observations in survey

The sum of the squared deviations decreases with the number of observations. In order to get significant estimations of the variation which is independent from the number of observations, a degree of variance is computed by summing up the squares (SS). In this case the degree of variance is the average quadratic deviation:

$$MS_t = \frac{SS_t}{df} = \frac{SS_t}{Z * I - 1}$$ **eq. 4-21**

$$MS_b = \frac{SS_b}{df} = \frac{SS_b}{Z - 1}$$

$$MS_w = \frac{SS_w}{df} = \frac{SS_w}{Z\,(\,I - 1\,)}$$

where: MS_t = average quadratic deviation
MS_b = average quadratic deviation between the classes
MS_w = average quadratic deviation within the classes
SS_t = sum of the squared total deviations
SS_b = sum of the squared deviations between the classes (explained deviation)
SS_w = sum of the squared deviations within the classes (unexplained deviation)
df = number of degree of freedom
Z = total number of specifications per attribute
I = total number of observations

The comparison of the values of MS_b and MS_w reflects the amicability of the used separation into classes. In case of MS_w = 0, the deviation around the total mean is only related to the separation into classes and, hence, there are no further influences on the dependent variable. As the probability of this case is rather small, an empirical F-value *F(emp)* is computed by the following equation:

$$F_{emp} = \frac{MS_b}{MS_w}$$ **eq. 4-22**

where: F_{emp} = empirical F-value
MS_b = average quadratic deviation between the classes
MS_w = average quadratic deviation within the classes

The higher the F-value, the stronger the relation between the chosen attribute and the number of trips. Furthermore, the theoretical F-value can be estimated based on the empirical F-value. The theoretical F-value reflects if there is a significant coherence between an attribute and the dependent variable. The following Table 4-6 shows the resulting empirical F-value for the person attribute age.

Table 4-6: Result of the ANOVA for the Attribute Age on Business Trips

Source of Variance	SS	MS	F(emp)
Between Classes	5,848	974.69	199.27
Within Classes	114,018	4.89	
Total	119,866	5.14	

Based on the presented approach which is carried out for the most important attributes described in the previous chapter the following classification of person attributes could be identified for business and private trip purpose. Regarding the short observation period of one week and the low probability of a tourism trip in this week, the explanatory power of attributes on tourism trips could not be analysed. For the trip purpose business, the variance analysis identified the employment status as most important person attribute, followed by the age class (demonstrated in the example), the household type in which the person lives and the car availability. For the trip purpose private, the age class of persons could be identified as most significant attribute concerning the explanatory power. According to the calculated empirical F-values, the attribute household type follows. Car availability and the employment status have a lower empirical F-value and, therefore, are not considered as significant attributes.

Regarding the socio-economic attributes that can be assigned to the population based on the endogenously computed output of other ASTRA-S modules, the age class has been determined as second attribute besides the personal monthly income. Even if the employment status could be identified as most important attribute concerning business trips, the significance of this attribute on private trips is only minor. The complexity of distributing the population into clusters of more than two attributes becomes obvious below. Additionally, the integration of more than two attributes, for example income, age and employment status, would decrease the number of persons per attribute cluster. The mentioned example would result in 140 possible combinations of attribute. Hence, the MOP could fulfil only in a small percentage of all combinations the rule of at minimum 50 persons per attribute cluster. Based on these constraints, the numbers of attributes for the trip generation model needed to be limited to income and age.

The major challenge in the preparation of the population segments covering all combinations of the determined two attributes constitutes the distribution of persons per income group to the specific age classes. In order to harmonise the trip generation model already in this stage, this allocation should be carried out by considering the share of persons per income group in the seven age classes that is reflected by the travel survey MOP. Hence, the participating persons are assigned to all imaginable 35 (seven age classes multiplied by five income groups) combinations of the two attributes. The average resulting share of persons within each income group per age class for the years 2002 until 2006 is used as factor for the basic estimation of the number of persons per attribute cluster. As this factor is derived by a panel and not by a census of the whole population of a country, the resulting sums of columns, representing the total number of persons per age class, and the resulting number of rows, reflecting the total number of persons per income group, have to be adjusted. The most adequate approach is the adjustment via FURNESS (1965) iteration. The implemented sequence of iterations consists of calculations which should compensate emerging deviations from sum of rows and columns to the target values provided by the income distribution and the population model. In total, ten iterations are required to minimise the deviations on both, total number of persons per age class and persons per income group.

4.4.2.3 Calculation of Passenger Trip Rates

Based on the determined person attributes which differentiate the population into five income groups and seven age classes the MOP database is analysed on average trip rates per person for each of the three trip purposes. As the German MOP members documented all trips within one representative week and the ASTRA-S trip generation model requires the number of trips per year, the number of trips is extrapolated. At first, the differentiation of trips into ten reasons is transferred into three trip purposes. Commuting, business/official and education trips are assigned to the trip purpose “business”. Shopping, leisure time, service trips, trips to secondary residence and short walking or cycling trips are allocated to the trip purpose “private”, while the tourism trips are not further distinguished in the German MOP. The last remaining reason in the MOP is the category of “trips with destination home”. As these trips can be the returning trips from business, private or tourism activities, they are assigned to the three ASTRA-S trip purposes according to the resulting share of trips per purpose on total number of trips. Table 4-7 illustrates the results of the MOP analysis in terms of average number of yearly trips per person for each attribute combination and all trip purposes.

Table 4-7: Basic Yearly Trip Rates per Person, Income, Age and Trip Purpose from MOP

Income Group	Trip Purpose	Age Class						
		0 to 17	18 to 25	26 to 35	36 to 50	51 to 59	60 to 69	70 plus
Low Inc	Business	502	448	375	416	462	324	300
Low-Med Inc	Business	522	459	475	535	480	278	181
Med Inc	Business	548	482	477	524	474	336	184
Med-High Inc	Business	513	542	470	481	483	355	317
High Inc	Business	671	385	483	508	513	368	251
Low Inc	Private	502	605	733	496	479	516	539
Low-Med Inc	Private	485	565	593	544	572	600	654
Med Inc	Private	538	621	639	605	561	673	620
Med-High Inc	Private	604	601	697	617	554	662	620
High Inc	Private	629	713	586	587	557	669	588
Low Inc	Tourism	9	17	24	9	6	6	6
Low-Med Inc	Tourism	10	15	17	9	15	15	19
Med Inc	Tourism	11	19	12	13	12	16	11
Med-High Inc	Tourism	13	15	19	16	15	13	6
High Inc	Tourism	12	14	12	11	10	18	10

Taking into account that at least 50 observations are required for each attribute cluster in order to ensure the reliability of resulting trip rates, the number of persons per attribute cluster have to be checked. The German MOP with only one trip documentation week entails that all attribute combinations for the purpose tourism are below the limit. Table 4-8 reflects that not only cells for tourism trips are under-represented in the German MOP. Even for the classification of persons into only two attributes, income and age, the marginal groups contain less than 50 persons. STOPHER/MCDONALD (1983) developed a method which is able to compensate resulting implausible trip rates per person for attribute clusters which are filled with less than 50 persons. The approach and its application are illustrated in the following.

Table 4-8: Persons per Income and Age Class that Documented Trips in the MOP

Income Group	Trip Purpose	Age Class						
		0 to 17	18 to 25	26 to 35	36 to 50	51 to 59	60 to 69	70 plus
Low Inc	Business	83	67	46	98	51	20	0
Low-Med Inc	Business	478	372	273	776	350	180	43
Med Inc	Business	277	290	392	1050	513	276	85
Med-High Inc	Business	9	28	161	313	143	93	28
High Inc	Business	3	37	230	572	300	217	52
Low Inc	Private	114	109	94	203	133	90	11
Low-Med Inc	Private	632	546	481	1399	750	867	375
Med Inc	Private	413	451	755	1802	932	1302	620
Med-High Inc	Private	12	40	267	540	296	397	172
High Inc	Private	5	69	390	928	567	800	278
Low Inc	Tourism	11	13	4	5	2	2	0
Low-Med Inc	Tourism	42	41	25	29	15	18	1
Med Inc	Tourism	17	38	37	56	40	31	26
Med-High Inc	Tourism	1	4	21	43	12	19	1
High Inc	Tourism	0	9	28	59	23	28	6

The so-called multiple classification analysis (MCA) contains, among other things, an alternative method for the Cross Classification. The single values of the trip rate matrices are adjusted by the following equations:

$$TR_{ig,ac}^{tp} = TR^{tp} + S_{ig}^{tp} + S_{ac}^{tp} \qquad \textbf{eq. 4-23}$$

$$TR^{tp} = \frac{\sum_{ig}\sum_{ac} OT_{ig,ac}^{tp}}{\sum_{ig}\sum_{ac} POP_{ig,ac}}$$

$$S_{ig}^{tp} = \frac{\sum_{ac} OT_{ac}^{tp}}{\sum_{ac} POP_{ac}} - TR^{tp}$$

$$S_{ac}^{tp} = \frac{\sum_{ig} OT_{ig}^{tp}}{\sum_{ig} POP_{ig}} - TR^{tp}$$

where: *TR* = trip rate per person of per trip purpose *tp,* income group *ig* and/or age class *ac*
OT = total number of trips per trip purpose *tp*, income group *ig* and/or age class *ac*
POP = population per income group *ig* and/or age class *ac*
tp = index for three trip purposes
ac = index for seven age class
ig = index for five income groups

A big advantage of MCA compared to the classical Cross Classification is the fact, that every single value of the trip rate matrix is not any longer based only on the survey values of this class. MCA considers for the calculation of each single value the whole amount of observed values of the respective means of columns and rows, as well as the total mean. Thus, trip rates of only marginally occupied household classes are based on significantly more observed values. Finally, this adjustment makes those trip rates more representative. A disadvantage of MCA is that the results of the displayed equations can also produce negative values in the trip rate matrix. Obviously, negative values reflect an incorrect adjustment, such that occurring negative values must be set on zero. This manual revision of implausible trip rates can result in deviations on the total number of trips, aggregated over all person clusters.

Table 4-9: Adjustment of Trip Rates based on MCA for Trip Purpose "Business"

Income Group	Age Class							Mean	Delta
	0 to 17	18 to 25	26 to 35	36 to 50	51 to 59	60 to 69	70 plus		
Low Inc	502	448	375	416	462	324	300	*438*	*-37*
Low-Med Inc	522	459	475	535	480	278	181	*482*	*7*
Med Inc	548	482	477	524	474	336	184	*479*	*4*
Med-High Inc	513	542	470	481	483	355	317	*461*	*-14*
High Inc	671	385	483	508	513	368	251	*471*	*-3*
Mean	*529*	*466*	*473*	*515*	*485*	*333*	*218*	*475*	
Delta	*54*	*-8*	*-2*	*40*	*10*	*-141*	*-257*		

Income Group	Age Class						
	0 to 17	18 to 25	26 to 35	36 to 50	51 to 59	60 to 69	70 plus
Low Inc	492	429	436	478	448	296	181
Low-Med Inc	536	473	480	522	492	340	225
Med Inc	533	470	477	519	489	338	222
Med-High Inc	515	452	459	501	471	319	204
High Inc	525	463	469	512	481	330	215

Table 4-9 demonstrates the application of MCA and the resulting yearly trip rates per person for the trip purpose "business". The final trip rates that are integrated in the trip generation model are shown in Table 4-10. The presented trip rates are only used to estimate the number of trips in those 18 countries which are covered by the income distribution model (see section 4.3.2). Trips made by the population of the remaining ten countries of EU27+2 are computed with the previous trip rates. Chapter 3.2.4.1 depicts the estimation of country-specific trip rates for those countries.

Table 4-10: Final Yearly Trip Rates per Trip Purpose for all Person Clusters

Income Group	Trip Purpose	Age Class						
		0 to 17	18 to 25	26 to 35	36 to 50	51 to 59	60 to 69	70 plus
Low Inc	Business	492	429	436	478	448	296	181
Low-Med Inc	Business	536	473	480	522	492	340	225
Med Inc	Business	533	470	477	519	489	338	222
Med-High Inc	Business	515	452	459	501	471	319	204
High Inc	Business	525	463	469	512	481	330	215
Low Inc	Private	453	545	575	526	504	594	568
Low-Med Inc	Private	476	568	599	550	527	617	591
Med Inc	Private	525	617	648	599	577	667	640
Med-High Inc	Private	539	631	662	613	591	681	654
High Inc	Private	516	608	639	590	568	658	631
Low Inc	Tourism	10	16	14	12	12	15	10
Low-Med Inc	Tourism	10	16	14	12	12	15	10
Med Inc	Tourism	10	17	15	12	12	16	11
Med-High Inc	Tourism	12	19	17	15	14	18	13
High Inc	Tourism	9	16	14	11	11	15	10

4.5 Vehicle Fleet Module

The fourth module which has been modified for the purpose of this thesis is the ASTRA Vehicle Fleet (VFT) module. Chapter 3.7.2 depicts the structure of the passenger car model that is integrated in the ASTRA VFT module. The passenger car model can be differentiated into three sub-models:

- the car registration model,
- the car technology choice model and
- the car stock model.

The adjustment of the VFT module covered in total three different parts of the complete module. The first adjustment is described in the following chapter 4.5.1. This chapter presents the revision of the car registration model which is responsible for the simulation of the decision of car purchasers for a certain representative car technology and car size. Due to growing importance of reduction of transport emissions, especially of CO_2 emissions in the context of climate change, a comprehensive simulation model like ASTRA requires a model that allows the estimation of technological scenarios. Hence, the differentiation between cubic capacities and the two conventional drives gasoline and diesel is not sufficient anymore. Ergo, the most promising alternative car technologies like electric or hydrogen cars are added to the passenger car model. Furthermore, the ex-ante version of ASTRA only considered emission standards up to Euro 4 category. Therefore, the second modification is related to the update of all simulated vehicle fleets (car, bus, light and heavy duty vehicles) with recent and future emission categories like Euro 5, Euro 6 and a probable Euro 7, that are influencing the development of emissions by transport. The third required adjustment of the VFT module is the consideration of income group dynamics as input. This input should provide further significant constraints to the car registration model which estimates the development of motorisation per country. This section concludes with the description of the implementation of this mechanism in ASTRA-S.

4.5.1 Car Technology Choice Model

The former version of the ASTRA Vehicle Fleet (VFT) module consisted of four separate models representing the passenger car, bus, light duty vehicle (LDV) and heavy duty vehicle (HDV) fleets in EU27+2 countries. The major indicator simulated by each of the four models is the number of vehicles in each country for the simulation period. There is a common structure implemented which is characterised by a feedback between new vehicle purchases per year the number of vehicles per age class, the scrapping of vehicles per year and a generated demand regulating the change of vehicle fleets and the re-placement of scrapped cars and therefore the new registered vehicles per year.

In contrast to the ASTRA bus and HDV model, the passenger car and LDV model differentiate between diesel and gasoline driven motors. Furthermore the former version of the car fleet model distinguished between three different cubic size groups for gasoline driven cars and two groups for diesel driven cars. All previous models differentiate emission categories (ece1503 until Euro5) determined by their date of purchase in common. The demand driving the change of fleet by new registrations is implemented in a different way in the four models. Bus, LDV and HDV new registrations are induced by vehicle-km driven in the respective freight transport model. For instance LDV registrations are modelled to be dependent on vehicle-km driven in local, regional and medium distance bands, while HDV registrations depend on longer distance vehicle-km driven.

Climate change set new challenges on technology and policy-making. One of the major objectives of the ASTRA-S model was to integrate new alternative car technologies in order to enable realistic impact assessments of technological and climate change scenarios. The revision of the VFT module was carried out in the context of the TRIAS project which concentrated on the analysis of impacts of promoting hydrogen and biofuel technologies. In order to simulate the potentials of hydrogen and biofuels as prospective vehicle technologies, the passenger car model was enhanced by six new car technologies. Figure 4-16 highlights the six new alternative car technologies besides the five already existing conventional car categories. Hybrid cars (HYB) comprise a combination of combustion and electric motors, whereas the modified model does not distinguish between hybrid cars equipped with diesel respectively gasoline motors. An exogenous share of diesel and gasoline HYB cars is estimated to assign the emissions and fuel consumption to diesel respectively gasoline technology. As many contemporary conventional diesel cars allow driving with biodiesel the new car category bioethanol cars (BIO) does only contain cars driving with bioethanol of type E85. Finally, the new category hydrogen car (H2) is implemented and incorporates fuel cell cars as well as cars with direct combustion engines. Regarding the current low frequency of filling stations offering alternative fuels, the automotive industry developed many alternative fuel cars that can be driven by conventional fuels as well, so-called flexi-fuel cars. The revised car fleet model allocates these hybrid car categories to the alternative fuel categories and not to the conventional car categories.

Conventional

- GPC1 (Gasoline < 1.4 l)
- GPC2 (Gasoline > 1.4 ∩ < 2.0 l)
- GPC3 (Gasoline > 2.0 l)
- DPC1 (Diesel < 2.0l)
- DPC2 (Diesel > 2.0 l)

Alternative

- CNG (Compressed Natural Gas)
- LPG (Liquified Petroleum Gas)
- HYB (Hybrid)
- ELC (Electric Current)
- BIO (Bioethanol E85)
- H2 (Hydrogen)

Figure 4-16: Overview of ASTRA-S Passenger Car Categories

The decision to purchase one of the five conventional car categories in the previous ASTRA car fleet model was driven by aggregated factors like differences between gasoline and diesel fuel prices, different taxation and a factor representing current trends. In order to integrate the new alternative car technologies, major factors that influence the decision of purchasers are identified. Several US studies and the most recent ARAL (2005) study elaborated via costumer surveys potential factors influencing the decision of a car purchaser for a certain car respectively car technology. In the following the European study from Aral is focused, as the new purchase decision model simulates the EU27+2 markets. Figure 4-17 provides a detailed overview of the survey. According to this study the costumers set a high value on economic efficiency for new cars. Price in combination with the provided performance of a car is the most significant factor with 55 % followed by the mileage of the car. Compared with older surveys the factor safety lost significance but, nevertheless, safety still plays an important role for 47 % of all interviewed customers. Besides economic and technical factors influencing the car purchase decision the study included also soft factors like design, image and prestige. In contrast to the economic factors they are supposed to be not as important. The low importance of factors like the environmental-friendliness of a new car indicates that alternative fuel cars can only diffuse successfully into the European markets when they can be purchased and operated for an adequate price.

Based on the cognitions of this survey and the feasibility to quantify drivers in a System Dynamics model the modified car fleet model concentrates on the economic efficiency as major impact for the purchase decision.

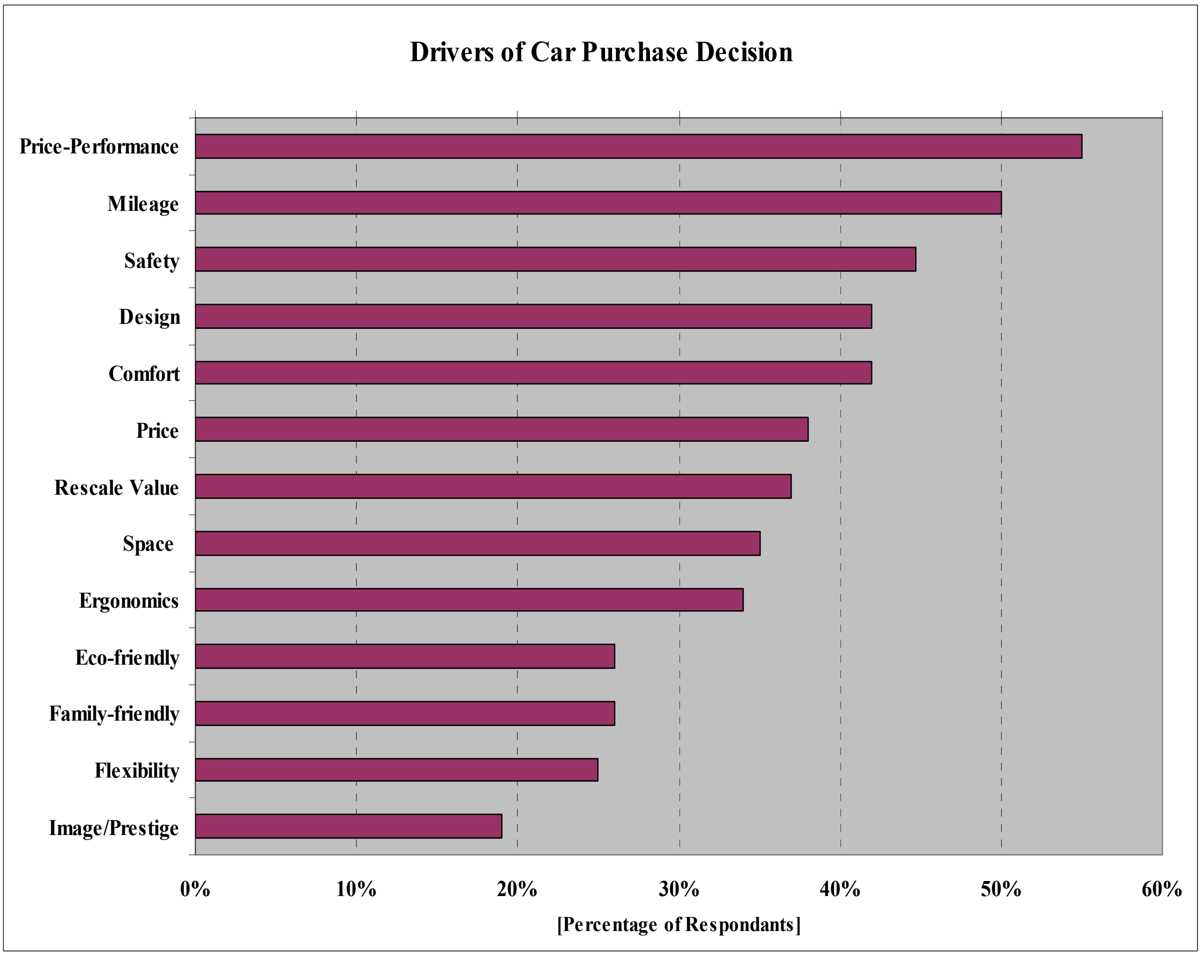

Figure 4-17: Drivers of Car Purchase Decision

Due to the characteristics of the purchase as a discrete choice for one out of eleven car categories respectively technologies, a logit-model is supposed to be the most sophisticated approach for simulating this decision. The implemented logit-function requires specific user benefits of all eleven car technologies that can be chosen. Similar to the application of logit-functions in the modal-split transport modelling stage this model does not compute benefits but costs that can be put into the logit-function as negative benefits according to the following equation.

$$P_{cc,i} = \frac{\exp(-\lambda_i * pC_{cc,i} + LC_{cc,i})}{\sum_{cc} \exp(-\lambda_i * pC_{cc,i} + LC_{cc,i})} \qquad \textbf{eq. 4-24}$$

where:
- P = share of purchased cars per car category *cc* and country *i*
- pC = perceived total costs per vehicle-km per car category *cc* and country *i*
- λ = multiplier lambda per country *i*
- LC = logit const per car category cc and country *i* representing the disutility
- cc = index for eleven car categories/technologies
- i = index for EU27 countries plus Norway and Switzerland

The modified car fleet model calculates the required average costs per vehicle-km for each car category in a bottom-up approach. First, the model computes variable costs per vehicle-km based on average fuel consumption factors for each technology and country-specific fuel prices provided by the POLES model described in KRAIL ET AL (2007). Fuel consumption factors for conventional cars are derived from HBEFA (2004). Available sales figures for specific car types for each alternative car category and general information from Original Equipment Manufacturers (OEM) are used to generate average fuel consumption factors for the six new car categories.

Besides variable costs the model also considers fixed costs for each car category. Fixed costs per car category and country are determined by car-ownership taxation, registration fees and purchase costs per country and car category as well as country-specific average maintenance costs. All elements of fixed costs are transformed into costs per vehicle-km by the division of average yearly mileages per car category and country. Average values for yearly mileages are based on car passenger-km and car-ownership taken from *"Energy and Transport in Figures"* (CEC-DGTREN 2005) and average occupancy rates taken from the TRANSTOOLS (CHEN ET AL 2005) model. As the conversion of purchase costs into costs per vehicle-km requires information on average lifetime per car category, this is derived from the car stock cohort model via feedback loop. Similar to the approach for computing the average fuel consumption factors for alternative fuel cars, average purchase costs for alternative fuel cars consider sales figures from the last years.

Assuming completely rational purchase decision behaviour based on all variable and fixed costs would disregard other important drivers like the distribution grid of filling stations selling the requested type of fuel. For conventional fuel types like gasoline and diesel the distribution grid is characterised by a good quality in all EU27+2 countries. At present, owners or prospective costumers of alternative fuel cars have to cope with the burden that the procurement of alternative fuels requires significantly longer additional trips or is even not feasible due to lacking filling stations. JANSSEN (2004) concluded in his paper on CNG market penetration that successful diffusion of new car technologies depend on a uniform development of technology and filling station infrastructure. Taking into account these significant impacts due to fuel supply differences, the model has to consider the quality of filing station grids as well. Hence, the four mentioned cost categories have to be completed by so-called fuel procurement costs.

In order to generate these costs per vehicle-km for each car category and country the model requires input in terms of filling station numbers for each fuel category diesel, gasoline, LPG, CNG, electric current, E85 and hydrogen. Conventional filling stations are derived from national statistics offices and automobile associations. Alternative fuel filling station numbers were taken from European Natural Gas Vehicle Association[18] and other databases[19]. Due to the lack of information about the spatial distribution of filling stations the modified model assumes a homogenous distribution. This leads to an average surface area for each fuel category that has to be served per filling station. The model considers the optimisation efforts of mineral oil groups in locating new filling stations efficiently by assuming a central location in a unit circle representing the average surface area. In order to calculate an average distance that has to be driven for refuelling a car three situations for the car-owner are conceivable:

[18] European Natural Gas Vehicle Association (ENGVA): http://engva.org

[19] Data taken from: http://www.gas-tankstellen.de, http://www.erdgasfahrzeug-forum.de and http://www.h2stations.org

- refuelling requires no extra trip because the filling station is located on the way to another destination,
- refuelling requires an extra trip for the car-owner starting in an area near the filling station (25 % of maximum distance) or
- refuelling requires an extra trip for the car-owner starting in an area far away from the filling station (75 % of maximum distance).

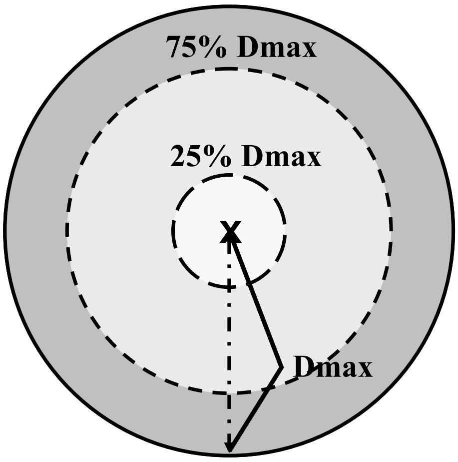

Figure 4-18: Estimation of Average Distance to Filling Station

Weighting the option without extra-trip by 25 %, the situation near by 50 % and the far away option by 25 % the model simulates an average trip distance for each refuelling action. Average cruising ranges per car category allow the calculation of total yearly kilometre that have to be driven for refuelling a car with a certain technology. Finally the model simulates the fuel procurement costs by multiplying the yearly kilometres with fixed and variable costs per vehicle-km and adding the opportunity costs generated via value of time and required time for the procurement trips extracted from the ASTRA-S Transport (TRA) module.

The following equation describes the simulation of perceived total car costs per vehicle-km that are composed of variable/fuel, purchase, taxation, maintenance and fuel procurement costs. Furthermore the model considers the importance of the purchase costs level for the calculation of perceived costs by setting a car category and country- specific weighting factor.

$$C_{cc,i} = \alpha_{cc,i} * pC_{cc,i} + taxC_{cc,i} + mC_i + vC_{cc,i} + procC_{cc,i} \qquad \textbf{eq. 4-25}$$

where:
- C = perceived car cost per vehicle-km per car category cc and country i
- pC = purchase cost per vehicle-km per car category cc and country i
- $taxC$ = taxation/registration cost per vehicle-km per car category cc and country i
- mC = maintenance cost per vehicle-km per country i
- vC = variable/fuel cost per vehicle-km per car category cc and country i
- $procC$ = fuel procurement cost per vehicle-km per car category cc and country i
- α = weighting factor representing the significance of purchasing costs
- cc = index for eleven car categories/technologies
- i = index for EU27 countries plus Norway and Switzerland

Finally, the logit function simulates the probability of cars purchased for each of the eleven technologies based on the simulated perceived car costs. Figure 4-19 gives an overview of the implemented approach for simulating the share of each technology on total cars registered. An optimal set of parameters could be identified for the weighting factor α, logit parameter λ and the logit const *LC* in the process of calibration. All parameters are calibrated with the Vensim® internal optimisation tool. Time series data for car registration per country disaggregated into car categories are taken from EUROSTAT (2007) online database. Several lacking datasets, especially for alternative fuel car registrations, required further data sources like data from ACEA and other.

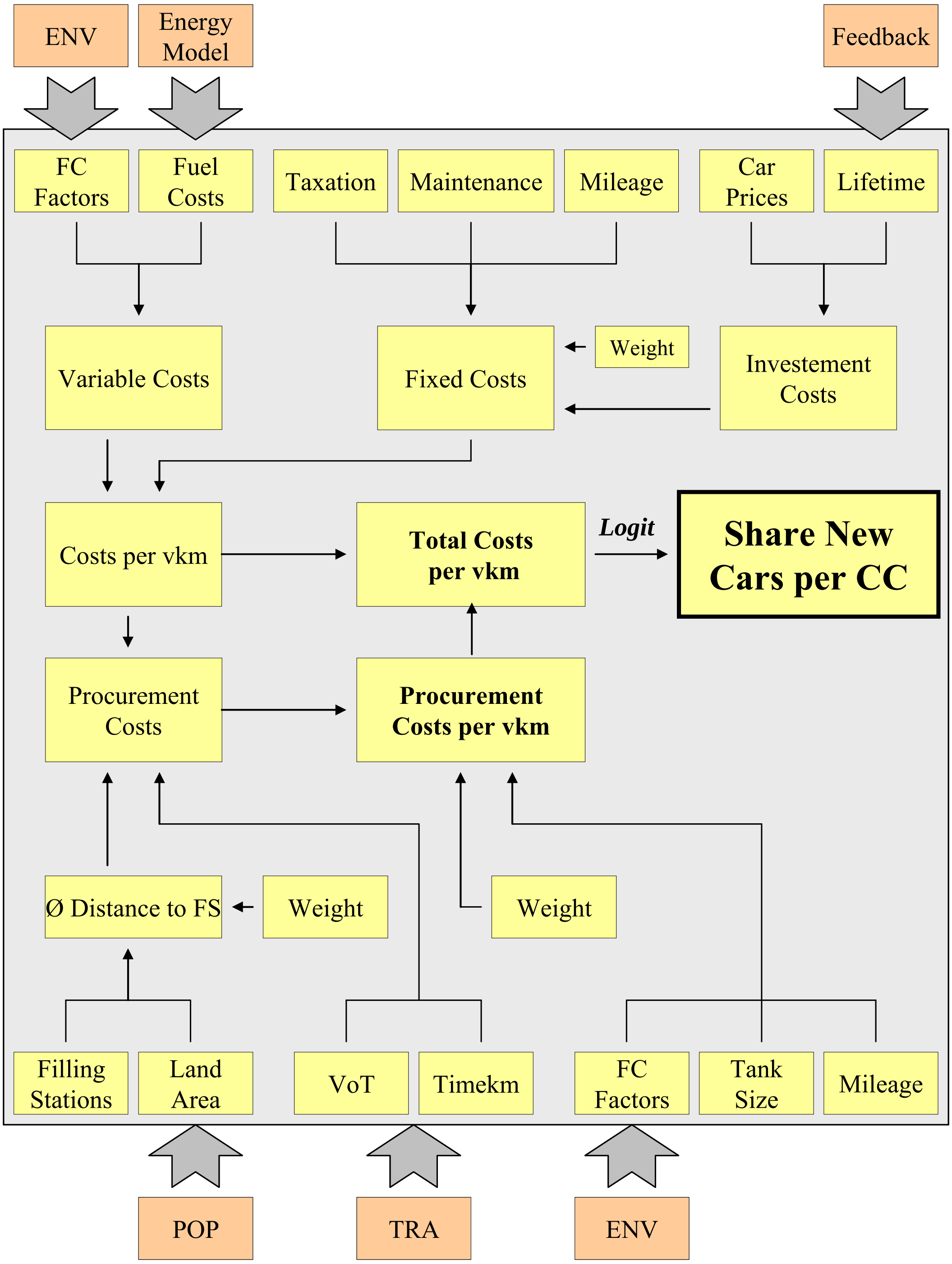

Figure 4-19: Overview of ASTRA-S Car Purchase Model

After simulating the share of new cars per car category with the new car purchase model this share is multiplied with the total number of new cars registered per country. Figure 4-20 demonstrates the implemented feedback loop in the car fleet model. Starting with an initial share of cars per car category, emission standard, country and age for each simulation period the new purchased cars are added while all scrapped cars in the different age cohorts are subtracted by the model. The number of scrapped cars is one of the drivers of total new registered cars per year, as the model assumes that a certain share of all scrapped cars is replaced by new ones. Furthermore new registrations per year are assumed to be dependent on the development of variable costs for operating a car, population, population density, average car prices, the level of motorisation and the average income per adult. Population density as a representative for urbanisation, car price, fuel prices and the level of motorisation dampen new registrations while income per adult and population foster new registrations.

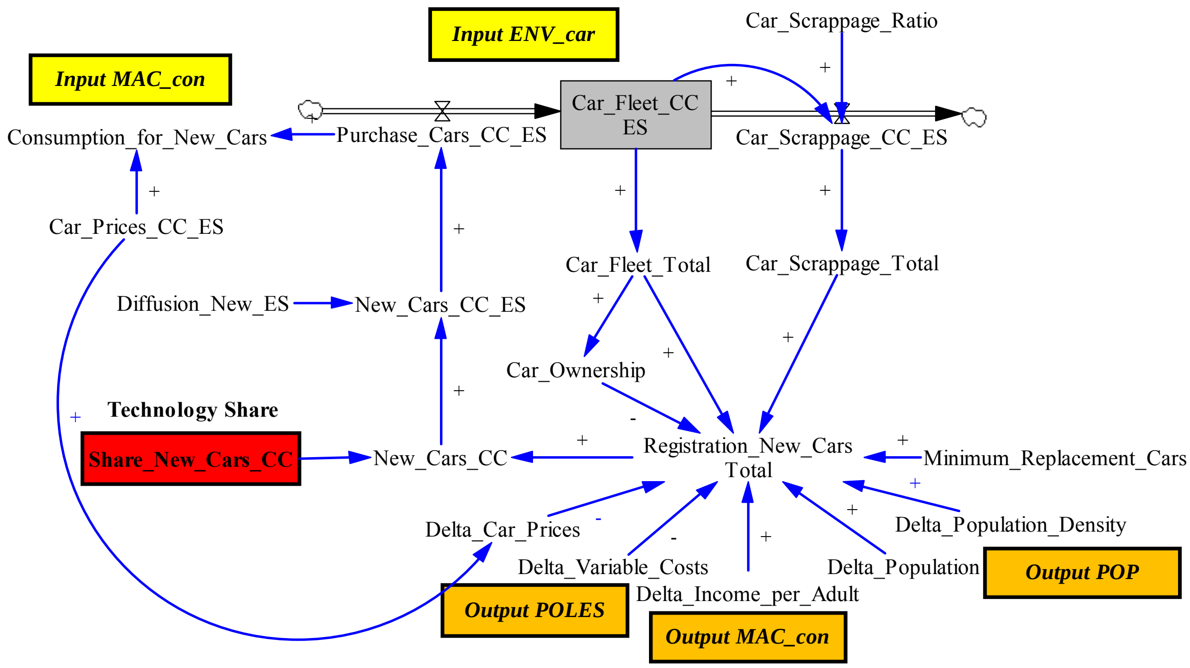

Figure 4-20: Overview of ASTRA-S Car Fleet Model

Figure 39 illustrates a representative result and highlights the dynamic modelling of emission standards in the car fleet model. The figure demonstrates the development of the diesel car stock per emission category in Germany from 1990 to 2050. The total number of diesel cars with cubic capacities less than 2.0 litres is increasing significantly until the year 2010. All other curves represent the life-cycle dynamics of emission standards until the projected Euro7 category. New purchased cars fulfil per definition the Euro7 standard after the year 2020. Caused by the small intervals between the introductions of new emission standards in Europe, the life-cycle curves are characterised by strong growth in the first years and a continuous decrease when the new standards enter the market.

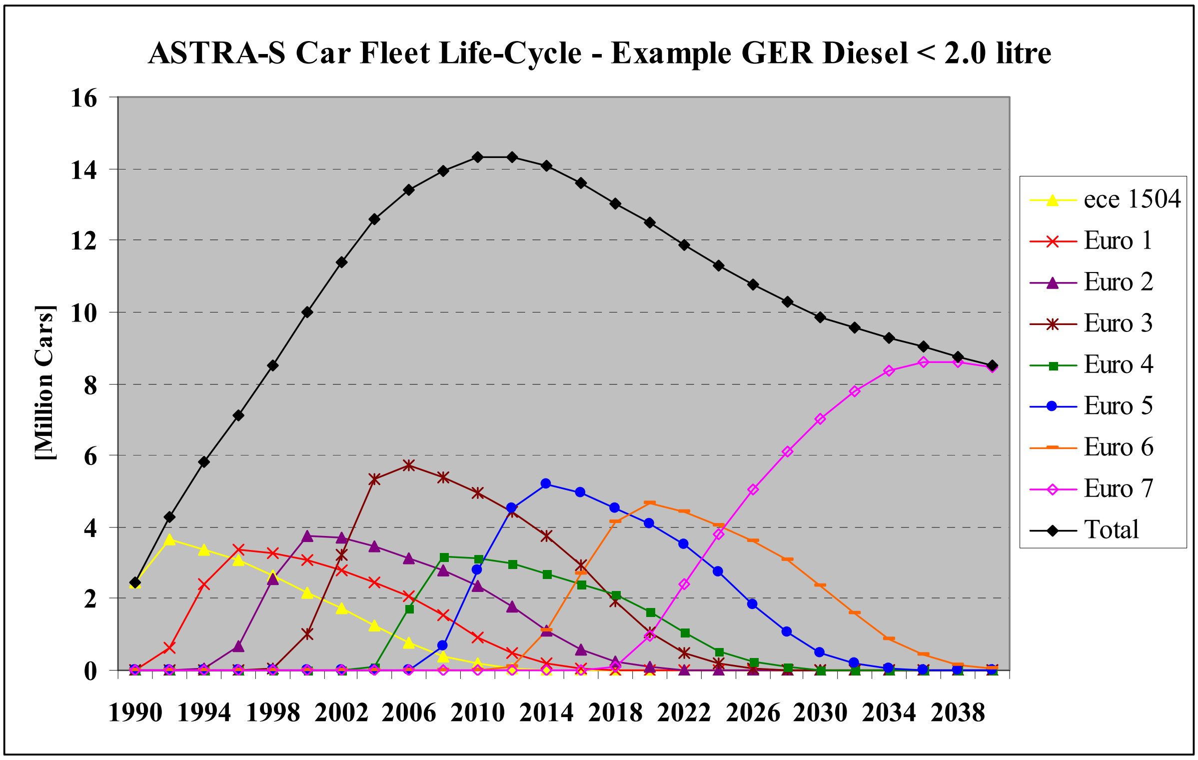

Figure 4-21: Example for Car Life Cycle Modelling in ASTRA-S VFT

Finally, the model disaggregates the new cars into car categories respectively technologies via the share generated in the car purchase model. Based on pre-defined diffusion years for all modelled emission categories, the number of new cars per car category and country are assigned to the according emission standards. Table 25 shows all emission standards and their assumed diffusion time implemented in the ASTRA-S model. In contrast to the ex-ante version of the ASTRA VFT module, the new version includes Euro 6 and Euro 7 emission standards. According to a directive of the European Parliament, the year 2014 is proposed as year of introduction for Euro 6. Based on the average interval between the introductions of two emission categories, Euro 7 standard cars are assumed to diffuse into the markets in the year 2020. The new emission standards Euro 6 and Euro 7 are integrated as well in the bus, light duty and heavy duty vehicle models with the same chronological schedule as in the car fleet model.

Table 4-11: Diffusion of European Emission Standards in ASTRA-S

Standard	Introduction Year
ece 1503	-
ece 1504	-
Euro 1	1991 - 1992
Euro 2	1994 - 1996
Euro 3	1998 - 2000
Euro 4	2004 - 2005
Euro 5	2007 - 2008
Euro 6	2012 - 2014
Euro 7	2018 - 2020

Similar to the car purchase model the car fleet model is calibrated based on EUROSTAT car fleet and aggregated new registration data. The calibration tool in Vensim® optimises weighting factors for all mentioned drivers of new car registration plus the vehicle-age-specific scrapping factors. According to observed historical correlations and results of the optimisation the demographic development, changes in income per adult and variable cost changes prove to be the most important drivers of motorisation. The following paragraph describes the revision of the car registration model based on the new income distribution information generated in the MAC module of the ASTRA-S model.

4.5.2 Car Registration Model

This chapter presents the adjustment of the car registration model. As opposed to the ex-ante ASTRA model, the established ASTRA-S income distribution model provides further significant inputs for the simulation of motorisation trends. The basic idea of the original car registration model was promising. Trends of average income per adult derived from the MAC module, fuel price from exogenous studies or models like POLES (see KRAIL ET AL 2007), average car prices from studies and demographic trends like population growth or change of population density were considered as main drivers of motorisation increase. In the course of the data analysis and the calibration, average income of adults emerged as most significant driver of the change of car fleets. The ex-ante ASTRA model computes average income per adult for each country by using the national accounting framework. Statistically, the incomes of the richest part of the population increased significantly, while the population allocated in the lower income groups partially had to cope with the reduction of average incomes in real terms. As the former ASTRA model does not consider the distribution of income among the population, the increasing income of the rich part of the population in EU27+2 overcompensates reductions of income of the poor part of the population, such that the resulting average income per adult indicates a growth of average income in real terms in most EU27+2 countries. After all, this aggregate view on reality leads to an overestimation of motorisation growth rates. In the ex-ante ASTRA model, motorisation played a significant role in the simulation of passenger transport performance trends. Two stages are assumed to be influenced directly via motorisation: passenger trip generation and modal split. Hence, too optimistic projection of motorisation influences the passenger transport performance in two ways. First, the number of trips increases as mobility surveys indicate higher trip rates for motorised persons. Secondly, a higher motorisation impacts the modal split stage. The model simulates a higher modal share for trips by cars. This problem has already been realised in the first calibrations of the car fleet model. In order to get this effect under control, an exogenous resistance variable has been integrated in terms of a lookup variable which reduces the growth of motorisation in case the motorisation reaches levels of more than 400 cars per thousand inhabitants. Up to the level of 700 cars per thousand inhabitants the resistance factor is moderate, above 700 the factor reduces the significance of income growth to a minimum.

The main objective of the modification of the car registration model is the implementation of additional information. This is derived from the income distribution model in terms of potential car purchasers. In other words, the aim of the adjustment is to redundantise the exogenous resistance factor and to link the development of motorisation with social trends that have been observed in real-world systems. In the following, the chosen approach for the implementation of income distribution impacts is presented.

As described in section 4.3.2 the ASTRA-S income distribution model does not estimate the development of the average income of all people in each income group. According to the model structure, only the absolute number of persons per income group can be used as input for the car registration model. Therefore, the original framework of the car registration model cannot be differentiated into income groups. Thus, the existing structure which determines the development of car registrations in the whole country is enhanced by a factor limiting the development of motorisation. The basic idea behind this new structure is that not everybody can afford to buy and operate a new or a used car. The income distribution model can provide the required information to estimate the potential car owners. The simulation of potential car owners requires two main inputs. The first consists of the average costs of a representative car for each income group. The second input is the monthly amount of money required for costs of living. It is obvious that both cost factors differ from one income group to another. Living costs of persons in the lowest income group often cross the poverty level, whereas persons in the highest income group have significantly higher living costs. Furthermore, the investment costs for new cars are on different levels among the income groups. While persons in low income groups are often forced to buy cheap and old used cars, persons in high income groups prefer often new luxury cars.

In order to compute the number of potential car owners, the costs for buying and operating a car have to be ascertained in a first step for all income groups separately. In the context of the car technology choice model, all variable and fixed costs for all eleven modelled car technologies were derived from statistics. The estimation of average monthly costs is carried out in several steps. The first step consists of the aggregation of average fuel, maintenance and taxation costs per vehicle-km (vkm). In a feedback process, the average yearly mileages per car technology are derived from the car stock model and used as input for the computation of resulting average costs per month for each car technology. Finally, average investment costs need to be added. Therefore, a simple assumption is made. The model prerequisites that persons in the lowest income group prefer on average used cars that range between 1,000 and 2,000 Euro, while persons in the highest income group usually buy new cars within a range of 18,000 to 50,000 Euro. The country with the highest GDP per capita in Europe in 2005, Switzerland ranges has a range between 2,000 Euro and 50,000 Euro from lowest to highest income group, while Romania with the lowest GDP per capita in the year 2005 is assumed to lie between 1,000 and 18,000 Euro. Linear interpolation according to GDP per capita compared with both countries is carried out so that all countries have a different range in which the average investment costs per cars for each income group vary. Regarding recent financing services of OEMs in Europe, the investment costs are estimated to be paid in monthly instalments over 36 months without interest payments. Based on this information and the share of new car registrations per car technology, monthly costs of a representative car for each income group could be derived. The following equation pictures the computation of average monthly car costs per income group:

$$C_{i,ig} = \sum_{cc} \left[\frac{taxC_{i,cc} + mC_i + vC_{i,cc}}{12} * shRC_{i,cc} \right] + \frac{pC_{i,ig}}{36} \qquad \textbf{eq. 4-26}$$

where: *C* = monthly car cost per car income group *ig* and country *i*
pC = purchase cost per income group *ig* and country *i*
taxC = taxation/registration cost per vehicle-km per car category *cc* and country *i*
mC = maintenance cost per vehicle-km per country *i*
vC = variable/fuel cost per vehicle-km per car category *cc* and country *i*
shRC = share of new registered cars per car category *cc* in country *i*
ig = index for five income groups
cc = index for eleven car categories/technologies
i = index for 18 modelled EU27+2 countries

The final step consists of the estimation of living costs besides car costs for each income group and each country. The definition of the poverty level provides a good foundation for the estimation of minimal living costs. According to the definition of the poverty line in Germany, it is the sum of money required for physically surviving. The most important expenditures are foreseen for living, clothing, food and medical supply. In the year 2005 three different poverty lines were defined that are assigned to household situation and age. The poverty line for single persons is determined by 7,356 Euro per year. For couples 12,240 Euro and for children 3,648 Euro are assumed to be the lower limit regarding the essential needs. Based on the demographic structure, an average monthly amount of 447 Euro could be estimated. This value could be transformed to all other 17 modelled countries under consideration of pricing index for the four major consumer products mentioned. Hence, the estimated poverty line ranges between 587 Euro in Switzerland down to 211 Euro in Hungary.

The number of potential car owners should represent an upper limit of motorisation under the assumption that all persons that can theoretically afford to buy and operate a car actually become car owners. Hence, the estimated poverty line is applied for each income group, even if richer people have higher standards of living. The last step in the calculation of potential car owners foresees a division of the sum of average monthly costs and country-specific poverty line by the upper income bound of the respective income group. The resulting ratio can be regarded as a probability that a person in the respective income group can afford to own a car. Additionally, the developed approach considers the fact that rich persons could be owners of more than one car. Then, the probability would exceed 100 %. The following equation (eq. 4-27) describes the final calculation of potential car owners in terms of motorisation per country:

$$pMOT_i = \frac{\sum_{ig}\left[\frac{upIB_{i,ig}}{(C_{i,ig}+PL_i)} * INC_{i,ig}\right]}{POP_i} * 1000$$ **eq. 4-27**

where:
- *pMOT* = potential motorisation in cars per thousand inhabitants per country *i*
- *C* = monthly car cost per car income group *ig* and country *i*
- *PL* = poverty level per country *i*
- *upIB* = upper income bound per income group *ig* per country *i*
- *INC* = number of persons per income group *ig* and country *i*
- *POP* = total number of population per country *i*
- *ig* = index for five income groups
- *i* = index for 18 modelled EU27+2 countries

Finally, a ratio is computed out of the endogenously computed motorisation *eMOT* and the resulting potential motorisation *pMOT*. This ratio provides the input for a lookup variable which determines the saturation effect in terms of a factor reducing the endogenous growth rate of car fleet. Figure 4-22 illustrates this factor. The closer the endogenously computed motorisation *eMOT* gets to the potential motorisation *pMOT*, the lower the factor becomes which is multiplied with the endogenous growth factor of car fleet.

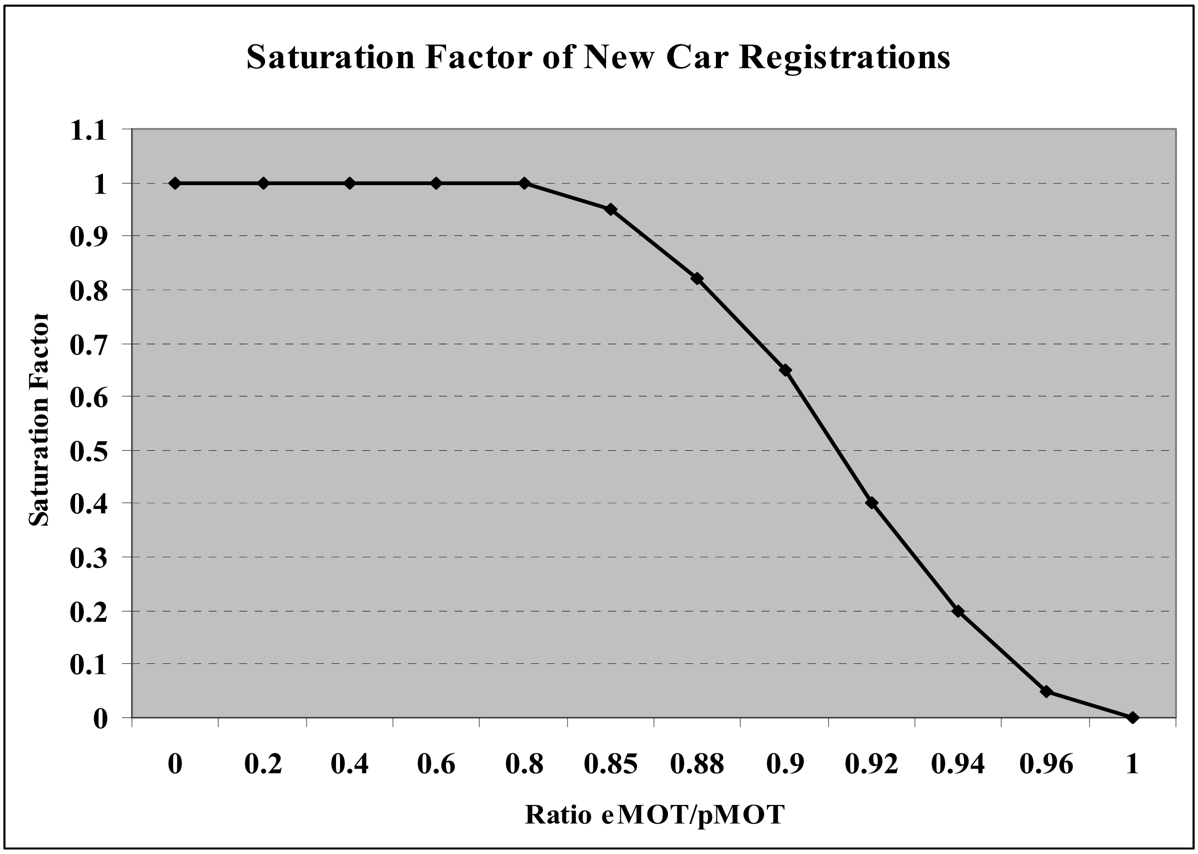

Figure 4-22: Saturation Factor Limiting Endogenous New Car Registration in ASTRA-S

As the ASTRA-S version of the income distribution model could simulate the income dynamics of only 18 out of all EU27+2 countries, the implemented saturation effect can only be applied for those 18 countries. The change in the car fleet of the remaining ten countries is modelled with the former ASTRA approach, using an exogenous resistance function.

4.6 Environment Model

In the context of the model revision and integration of new models in ASTRA-S, two main improvements of the environmental model are realised. The first modification of the environmental model consists in the integration of two further major air pollutants from transport: *carbon monoxide* (CO) and *volatile organic compounds* (VOC). The second revision is demanded, as six new alternative car categories are integrated in the passenger car fleet model. The existing models of the Environmental (ENV) module which have been mainly developed to estimate the air emissions of carbon dioxide (CO_2), nitrogen oxide (NO_x), sulphur dioxide (SO_2) and particulate matter (PM_{10}) by transport activity need to be enhanced. Finally, the last update of the ENV module consists of the revision of emission factors for new emission standards Euro 5, Euro 6 and an estimation of a possible Euro 7.

4.6.1 Integration of Further Air Pollutants

Talking about the impacts of conventional and alternative car technologies on climate change, another chemical compound besides CO_2 is often mentioned: methane (CH_4). Even if human beings, animals and plants are the main sources of methane, it is also emitted in the combustion process of gasoline and natural gas (CNG) engines. Hence, a comprehensive simulation of impacts of transport and technology scenarios on climate change should integrate methane as well. Methane is the most important element of volatile organic compounds (VOC) which also contain other chemical compounds. As car emission factors are often calculated for the whole group of VOC, this group is added as first further pollutant to the already covered CO_2, NO_x, SO_2 and PM_{10}.

Another pollutant that contributes to the greenhouse effect and global warming is carbon monoxide (CO). Especially in urban areas, CO reacts photo-chemically and produces peroxy radicals. Then, these radicals react with NO_x to increase the ratio of nitrogen dioxide (NO_2) to nitrogen monoxide (NO). Finally, this reduces the quantity of NO that is available to react with ozone. Carbon monoxide is generated from the partial combustion of carbon-containing compounds, mainly in internal-combustion engines of vehicles. Besides the impacts on global warming, CO is a toxic gas. Exposure to CO can harm the central nervous system and the heart of human beings. These facts led to the decision to implement CO as further pollutant in the ASTRA-S ENV module.

The calculation of emissions by transport activities in the ENV module is differentiated according to the source of the emissions. All modelled transport vehicles are considered as source of emissions: passenger cars, light duty vehicles (LDV), heavy duty vehicles (HDV), buses, trains, ships and planes. As described in section 3.2.8 and in detail by SCHADE (2005), the emissions are simulated for all transport modes in separate sub-models. The characteristics of the single sub-models are similar, as all models require transport performance in terms of vehicle-km and specific emission factors per vehicle category as input for the computation of emissions during the operation. These emissions are called hot emissions, as they occur during the operation of a vehicle, when the engine has reached an optimal combustion temperature. Hot emissions are modelled for all vehicle categories. The second emission type considered is the category of cold start emissions. Those emissions occur during the first minutes after starting a combustion engine. Hence, the number of trips is required. As opposed to hot emissions, cold start emissions are only considered for passenger cars. Additionally, fuel production emissions that are generated during the fuel production process, including the transport of fuels to the end consumer, are implemented for all transport modes. The last component of emissions implemented in ASTRA and ASTRA-S is the vehicle production emissions. New registrations of road vehicles are the major input for this emission type. Hence, they are only considered in the road transport emission models.

The new pollutants are integrated similarly in the single emission models for each transport mode. All four categories of emissions could be modelled for CO emissions as well. Hence, ASTRA-S simulates whole life-cycle emissions of CO. Regarding the characteristics of CO which are generated in partial combustion cold start emissions contribute a significant share to total CO life-cycle emissions. VOC emissions could be modelled for the categories hot, fuel and vehicle production emissions. The data source from which the emission factors per vehicle category and emission standard are extracted, HBEFA (2004), did not publish average VOC cold start emissions for passenger cars. All other CO and VOC emission factors could be derived from this data source.

4.6.2 Alternative Car Technologies and New Emission Standards

After completing the integration of alternative car technologies in the EU27+2 car fleets, the final step consists in the update of the ENV module. Emission factors for each new car category are required in order to simulate the emissions caused by transport activities with alternative fuel cars. Thereof, no structural change of the ENV module is necessary. The former ASTRA version applied already subscripts for car categories and emission standards. Those subscripts allow a well arranged model structure and simplify the integration of new categories in a group. Hence, the six new car categories could be considered by enhancing the subscript from five to eleven without changing the model structure.

According to the European Parliament, the proposed emission limits for new cars, documented in the Directive T6-0561/2006, were adopted for the CO, NO_x, VOC and particulate matters hot emission factors for conventional cars and light duty vehicles for Euro 5 and Euro 6 emission standard. According to the European Parliament CO and VOC hot emission factors remain on the same level for the emission standards Euro 4 to Euro 6. According to this technological stagnation CO and VOC hot emission factors for a coming Euro 7 emission standard are as well assumed to stay on the same level. In contrast to these pollutants, the proposed NO_x hot emission factors for Euro 5 standard decrease by -28 % for diesel and –25 % for gasoline cars and for Euro 6 standard even by –55 % for diesel while gasoline cars emission factors remain on the Euro 5 level. Nevertheless, due to missing studies on expected prospective NO_x hot emission factors, Euro 7 NO_x hot emission factors are assumed to remain on the Euro 6 level.

The only pollutant that is not included in the proposal of emission limits is CO_2. According to the recent EU directive focussing the reduction of average CO_2 emission factors for EU27 vehicle fleets of each automotive company, a reduction of -15 % CO_2 from Euro 5 to Euro 6 standard and –5 % from Euro 6 to Euro 7 standard is implemented for conventional cars in the ENV module.

Hot emission factors of compressed natural gas vehicles (CNG) are based on the most important OEMs of CNG cars (Opel, etc.). According to the automotive companies CO_2 hot emissions can be reduced on average by –25 % up to –30 % compared with average conventional gasoline cars. The improvement for CO hot emissions differ between -50 % up to –90 % reduction for CNG, while 85 % up to 90 % of NO_x hot emissions can be saved by CNG cars compared to average gasoline cars. VOC and PM_{10} hot emissions can be reduced to a minimum so that these hot emissions are assumed to be zero for CNG cars. Regarding the stated reduction ranges compared with average gasoline cars, CO_2, NO_x and CO hot emission factors of CNG cars can be estimated. The estimation is based on the average reduction rate and a comparison with the emission factors of the gasoline car category that has the highest share in EU27+2 car fleets: gasoline cars between 1.4 and 2.0 litre cubic capacity.

Table 4-12: Assumptions on Emission Reductions after Euro 7

Pollutant	Emissions	Mode	Fuel Type	2030	2040	Reduction based on	
						Year	Source
CO	hot	Bus	Diesel	-1%	-3%	2025	Euro 7
CO	hot	Car	All	-1%	-3%	2025	Euro 7
CO	hot	HDV	Diesel	-2%	-5%	2025	Euro 7
CO	hot	LDV	All	-1%	-3%	2025	Euro 7
CO	fuel production	All	Conventional	-10%	-18%	1997	MEET D20
CO2	hot	Bus	Diesel	-3%	-10%	2025	Euro 7
CO2	hot	Car	Gasoline	-5%	-15%	2025	Euro 7
CO2	hot	Car	Diesel	-5%	-10%	2025	Euro 7
CO2	hot	Car	Alternative	-5%	-10%	2025	Euro 7
CO2	hot	HDV	Diesel	-5%	-10%	2025	Euro 7
CO2	hot	LDV	Gasoline	-10%	-20%	2025	Euro 7
CO2	hot	LDV	Diesel	-8%	-15%	2025	Euro 7
CO2	fuel production	All	All	-15%	-20%	1997	MEET D20
NOx	hot	Bus	Diesel	-10%	-20%	2025	Euro 7
NOx	hot	Car	All	-10%	-25%	2025	Euro 7
NOx	hot	HDV	Diesel	-10%	-20%	2025	Euro 7
NOx	hot	LDV	All	-5%	-10%	2025	Euro 7
NOx	fuel production	All	All	-15%	-20%	1997	MEET D20
PM10	hot	Bus	Diesel	-10%	-20%	2025	Euro 7
PM10	hot	Car	Diesel	-5%	-15%	2025	Euro 7
PM10	hot	HDV	Diesel	-10%	-20%	2025	Euro 7
PM10	hot	LDV	Diesel	-5%	-10%	2025	Euro 7
VOC	hot	Bus	Diesel	-1%	-3%	2025	Euro 7
VOC	hot	Car	All	-1%	-3%	2025	Euro 7
VOC	hot	HDV	Diesel	-2%	-5%	2025	Euro 7
VOC	hot	LDV	All	0%	0%	2025	Euro 7
VOC	fuel production	All	Conventional	-10%	-18%	1997	MEET D20

Similar to CNG emission factors LPG hot emission factors can be derived from OEM information for the baseline and reference scenario. Compared with an average gasoline car LPG cars emit on average about –15 % less CO_2, -80 % NO_x, -80 % CO and –60 % VOC. Comparable to CNG cars soot particle emissions could be minimised for LPG cars, so that zero emissions are assumed. Hybrid car hot emission factors could be calculated based on OEM information for Toyota Prius, Honda Civic and Lexus. Bioethanol car hot emission factors were taken from Volvo company information on the so-called “flexifuel” cars. Finally, the model assumes hot emission factors for all pollutants for fuel cell respectively direct hydrogen combustion cars and electric cars to be zero. Emissions emerging in the fuel production process are considered in the category fuel production emissions (FPE). Country-specific average power plant emissions are considered for electric current emissions. The latter could be extracted from the MEET study (LEWIS 1997). Cold start emission factors for conventional cars were taken from the handbook of emission factors (HBEFA 2004). Emission factors projections for the year 2015 are implemented as Euro 6 standard, 2020 projections as Euro 7 emission standard.

Table 4-12 highlights the assumptions on emission reductions for all vehicles registered after Euro 7. Furthermore, fuel production emission reductions compared with the values generated in the MEET project are illustrated.

4.7 Model Calibration

The accurate consideration of model development rules, for example described by BOSSEL (1994), and a comprehensive research of statistical correlation of indicators does not guarantee an exhaustive description of the behaviour of systems reflected by the established model. As described in section 2, the modelling of complex social and economic systems can only provide a simplified picture of reality. In order to be able to provide a good basis for decision-making, models should consider uncertainties as well. The only way to integrate such factors and, therefore, to guarantee the validity of the model and allow the comparability with other models is the implementation of calibration parameters which are predefined according to their quantitative ranges by the modeller. The optimal value of the parameter is determined in the calibration.

The calibration of a large and complex system dynamics model like ASTRA-S is a stepwise, iterative process. The dimension of the ASTRA-S model including several million objects does not allow the calibration of the whole model within one calibration step. The very first step in the calibration of ASTRA-S is the fixing of important variables like GDP. This is done by replacing the endogenous variable by an exogenous variable filled with statistical data for the whole calibration period from 1990 to 2005. By this, feedbacks from the rest of the model on these variables are cut off. The new model behaviour is now influenced by the exogenous data and avoids the complex structure of the model where “everything depends on everything else". According to the degree of interaction and the data availability the ASTRA-S model is separated into so-called stand alone models which can be calibrated outside the complete ASTRA-S model. Sub-models with many exogenous inputs and few endogenous impacts are calibrated first. Then models with good data availability follow. Based on the knowledge of important feedback loops in the ASTRA-S model an optimal sequence of calibration of sub-models has been identified by SCHADE (2004). Figure 4-23 illustrates the calibration process and the optimal sequence.

The sub-models are calibrated so that the endogenous development of the major indicator deviates to a minimum from statistical data for the historical period from 1990 to 2005. After the sufficient completion of the calibration of a sub-model, the results are integrated as inputs for the calibration of the next sub-model according to the sequence. Finally, feedback loops are closed and results are checked so that deviations should not exceed an acceptable range. As the closing of feedback loops might change the results of the sub-models, the calibration process has to be repeated in the described sequence until the single deviations of most important indicators are adequate.

As far as possible the automatic calibration tools that are provided by the Vensim® software are applied. SCHADE (2004) developed calibration tools connected with Vensim® that allow the calibration of models containing large matrices. As described by Schade this process is similar to econometrics.

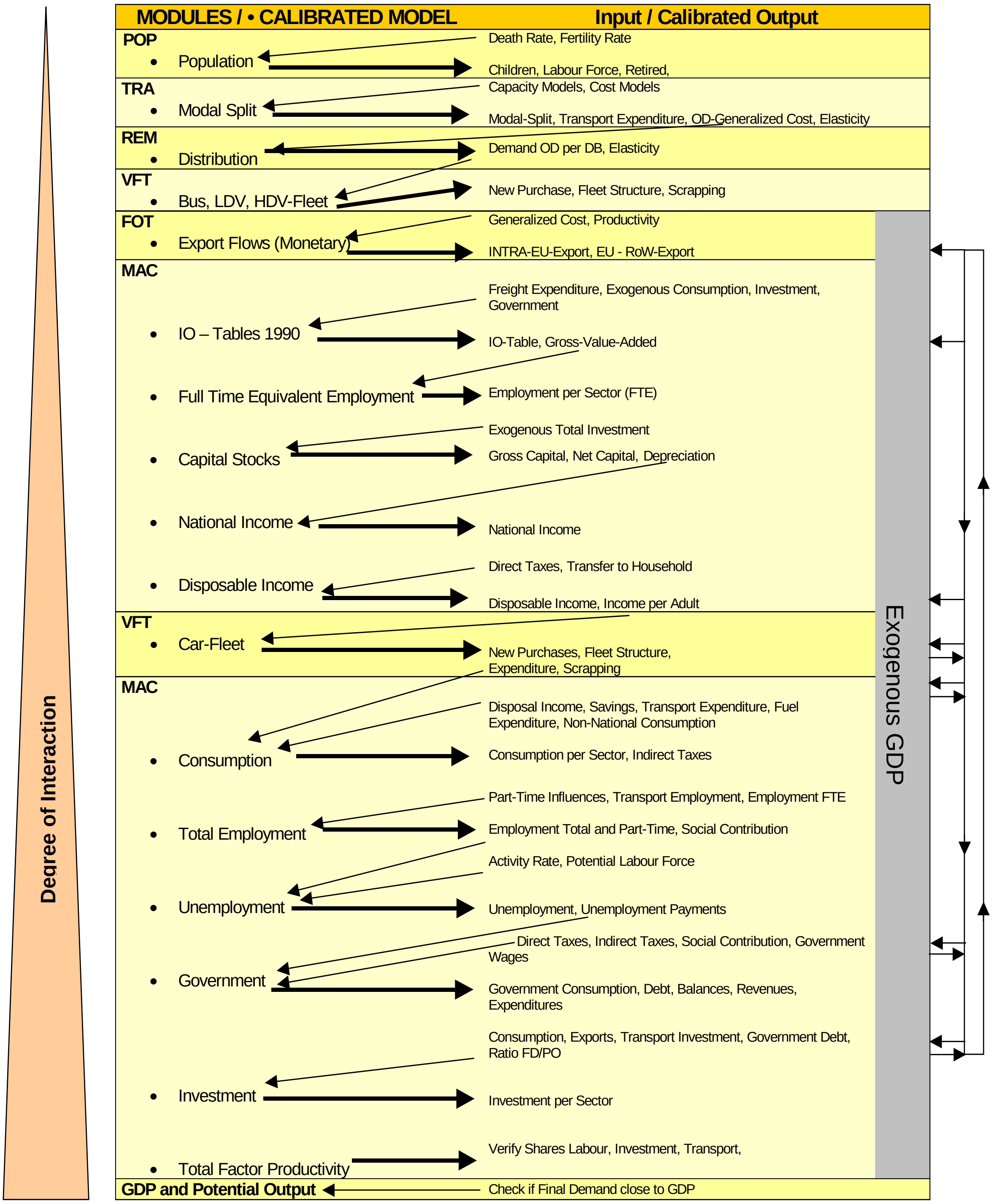

Figure 4-23: Sequence of Calibration of Sub-Models in ASTRA-S (SCHADE 2004)

The calibration of the ASTRA-S model is usually performed, when new modules are integrated in ASTRA-S that change or enhance the feedback structure of the ASTRA-S model significantly. In theory, it was imaginable that the models developed for this thesis might impact changes of results of the former calibrated ASTRA-S models for the calibration period between 1990 and 2005. In fact, only the final impacts of income distribution on passenger trip generation and vehicle fleets required the re-calibration of the passenger transport model.

5 Simulation Results and Analysis

The ASTRA-S model as well as the previous ASTRA versions are mainly developed and improved for one purpose: sustainability impact assessment of transport policies and strategies. Since the beginning of the model development, a number of impact assessment studies were performed with ASTRA. Sustainability trends of European countries, in terms of policy impacts on economy, transport and environment systems of several transport policies, were estimated. In the TIPMAC project (SCHADE/KRAIL et al. 2004), social marginal cost pricing, fuel taxation and transport infrastructure scenarios were studied. Several technological scenarios considering predefined, prospective diffusion of alternative fuel cars into EU27+2 markets were simulated during the LOTSE project (KRAIL/SCHADE 2004). The TRIAS project (KRAIL ET AL. 2007) focussed as well on sustainability impact assessment of scenarios supporting hydrogen or biofuels as on future energy source for transportation. Revenues generated by a carbon tax or subsidies were applied for the funding of hydrogen or biofuel infrastructure in Europe. Several other policies and strategies like the introduction of harmonised speed limits all over Europe, of CO_2 emission limits of vehicle fleets or high growth of oil prices were assessed with the ASTRA model in other projects.

Due to the characteristics of the ex-ante ASTRA model, impact assessment of transport, environmental and economic scenarios covering all three dimensions of sustainability was restricted. Impacts on the third dimension of sustainability, society, could only be illuminated by labour market indicators. Actually, those employment or unemployment indicators can be also allocated to the economic field. The modifications prepared for this thesis, concluding in the new ASTRA-S model version, enabled the simulation of another significant social indicator: income distribution respectively income inequality. Furthermore, the new heterogeneous income data allow a more detailed modelling of the first stage of the passenger transport model.

Transport, environment and technological scenarios influence income distribution only indirectly. As described in chapter 4.3.2.3, the ASTRA-S income distribution model considers several socio-economic indicators as drivers of income distribution. Most conceivable scenarios impact the development of economic indicators like employment or taxation. Transport pricing scenarios which were analysed with ASTRA several times in the past years lead probably to the most significant changes. Only the consideration of refunding mechanisms for transport pricing revenues via direct tax reductions would have direct effects on income distribution. Despite these direct effects, it is refrained from implementing and analysing transport pricing scenarios like social marginal cost pricing. At least social marginal cost pricing for passenger transport is only hardly applicable in reality with present road charging systems. In theory, the German high-technology system Toll Collect could be used for charging of passenger cars as well, but the level of costs of debt collection routines would inhibit economic success. Not to forget, that the system requires the integration of on-board-units in the total passenger car fleet. Therefore, no scenario is presented which influences the income distribution directly. Instead, this section depicts impacts of income distribution on mobility respectively the development of motorisation by comparing the simulation results with and without inputs of the income distribution model. For this purpose, the links from the income distribution model to the passenger trip generation and to the car registration model are switched to the status in the ex-ante ASTRA model.

The contribution of the car technology model to the improvement of ASTRA as a sustainability impact assessment tool is exemplified within a combined policy and technology scenario. The mentioned transport pricing represents only one of many possible actions in the transportation field to cope with the enormous challenge to limit global warming. Besides behavioural changes, caused by transport pricing, the technical progress of rolling stock obviously plays an important role. Years of intensive research and the development of alternative fuel cars brought the car industry in the position to start with mass production of alternative fuel cars like fuel cell cars already in the near future. As several examples (see JANSSEN 2004) told us, putting competitive alternative fuel cars on the market can only be successful if several other issues besides car and fuel price are taken into account. Most important, an adequate filling station infrastructure and a competitive hydrogen production industry must be developed in parallel. The combined technology and transport respectively climate policy scenario which is presented in this section considers these prerequisites. In order to generate relevant subsidies for an accelerated diffusion of hydrogen technology in the EU27+2 markets, a carbon tax will be implemented for all passenger modes.

Section 5.3 provides the definition of all assumptions for this scenario and the resulting impacts on economy, transport and environment. In order to visualise the changes caused by the scenario, a baseline scenario has to be defined at the beginning. A baseline scenario is also significant for the interpretation of changes caused by the new income distribution model and other model modifications for this thesis. The definition of the baseline scenario and projections of socio-economic, transport and environmental indicators for EU27 countries are depicted in chapter 5.1. All results of the combined technology and policy scenario are analysed and compared with the baseline scenario results.

5.1 Baseline Scenario

Policy analysis for future decision-making always requires at first the development of an idea of a probable future. This includes expected trends as well as consequences of already passed policies. The resulting picture of the future constitutes the baseline scenario or business-as-usual (BAU) scenario. The impact assessment of a technology and policy scenario prerequisites a baseline scenario as the policy scenario results can be opposed and compared with the baseline results. This section starts with a definition of the baseline scenario which is simulated in this thesis. After explaining the major assumptions integrated in the baseline scenario, projections until 2040 of most important socio-economic, transport and environmental indicators are presented.

5.1.1 Baseline Scenario Definition

The baseline scenario prepared for this thesis considers the policy framework set by already taken decisions as well as European transport strategy documents like the White Paper on *European transport policy for 2010: time to decide* (CEC 2001). The baseline scenario does not necessarily reflect the most likely or the most probable development. It serves as a projection considering rather optimistic assumptions on oil resources. This leads to fairly moderate growth of oil prices. The assumed slow growth allows a successive adaptation of economy and industry to meet the challenge of increasing mineral oil scarcity.

The baseline scenario at hand refers mainly to the baseline scenario developed within the TRIAS project (KRAIL ET AL. 2007). A major characteristic of the TRIAS project was the link between the ASTRA model and the energy model POLES (KRAIL ET AL. 2007, pp.10). In TRIAS, the POLES model was responsible for the generation of fuel prices and investments into fuel production facilities for all fuel types. As the POLES model could not be linked for the scenario simulation in this thesis, the values for energy prices and investments produced for the TRIAS project are integrated in the baseline scenario. Figure 5-1 presents the estimated development of fuel prices for the covered technologies. In the following the most important assumptions of the single ASTRA-S modules for the baseline scenario are highlighted.

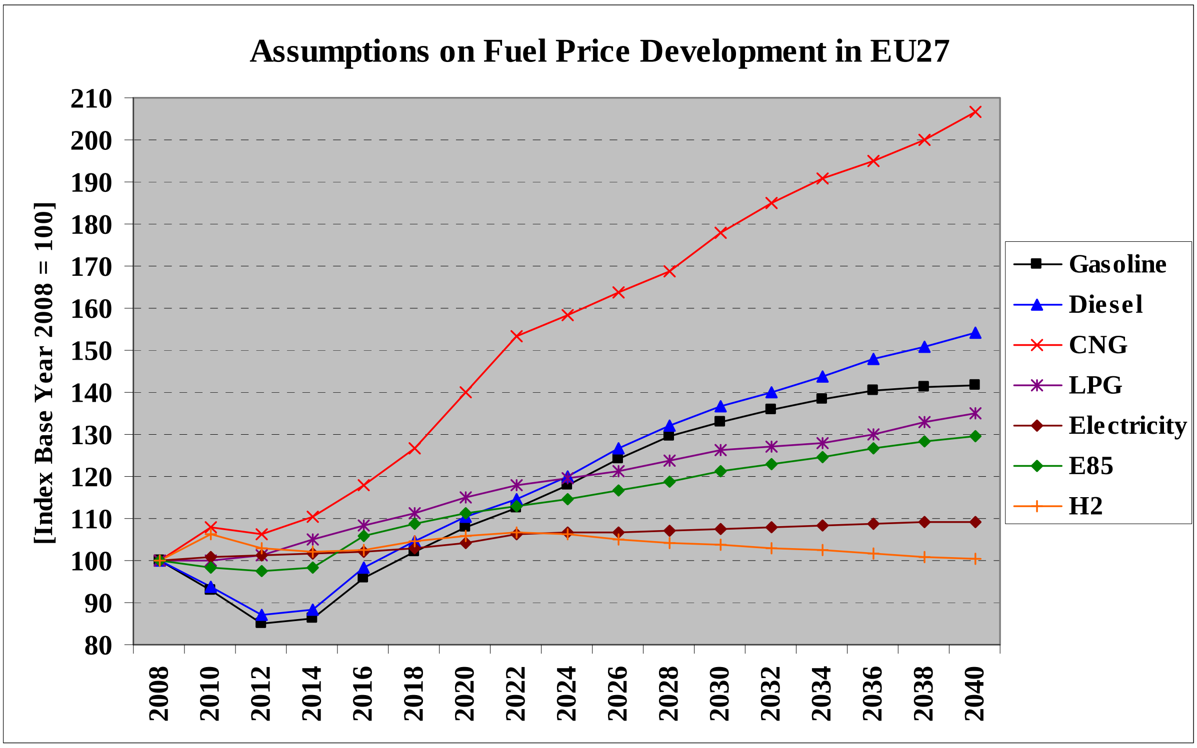

Figure 5-1: Fuel Price Development taken from POLES Model in BAU Scenario

Baseline scenario assumptions in the MAC module are mainly derived from previous studies, like the dissertation of SCHADE (2005). Within the TRIAS project, these assumptions were extended considering the time period from 2025 until 2040, and taking into account the value of 2025. Thus, an optimistic picture is drawn for certain exogenous trends. One example is the assumption of constant annual growth rates of labour productivity that are taken from 2025 to 2040. In the context of the income distribution model, further assumptions are added. The baseline scenario assumes a constant share of alumni for three defined ISCED97 levels until 2040. Furthermore, projections on future average monthly net incomes per age class and sector are determined for the baseline scenario. Even if in some countries the growth of income with increasing age seems to slow down, the EUROSTAT income numbers are kept constant for the future. Demographic projections demonstrate that the number of persons in working age is decreasing. Hence, qualified and experienced employees should be required in future as well. Therefore, no change of average income is considered in the baseline scenario. The assumption of constant average income per economic sector is the result of lacking information about the skills of available employees. Micro-level information about the skills of persons in working age and the average skill profile for employed persons in a specific sector are needed to estimate the development of wages per economic sector.

As opposed to the assumptions displayed in SCHADE (2005), the GDP development in countries outside Europe was changed. The so-called world GDP is a driver of exports in the Foreign Trade (FOT) module. A cyclical development is overlaid on simulation results of the project ADAM (2007).

The definition of a baseline scenario setting in the TRA module consists mainly in the definition of the prospective travel costs. Trasporti e Territorio (TRT) developed a bottom-up approach considering every single element of travel costs. For the development of these costs, assumptions were adopted from the ASSESS project (DE CEUSTER 2005).

Two categories of assumptions are implemented for the baseline scenario into the VFT module: assumptions on prospective cost development and general assumptions on diffusion probabilities of alternative car technologies. Car taxation is assumed to stagnate on the last available level for each country. Taxation rates and fees are taken for each country for historical period from 1990 to 2006. The second cost category that is influenced by the baseline scenario assumptions is the development of car prices for each of the modelled eleven car categories. Basic prices are taken from the year 1995 for the conventional gasoline and diesel cars and from the year 2005 for alternative technologies. Bioethanol and hydrogen car price assumptions were taken from the hydrogen and biofuels database developed for the TRIAS project. Table 5-1 demonstrates the different assumptions on car price development.

Table 5-1: Assumption on Car Price Development per Technology in EU27+2

Car Technology	Car Price Development		
	2020	**2030**	**2040**
Conventional	25%	38%	41%
CNG	13%	17%	19%
Hybrid	13%	17%	19%
Electric	13%	17%	19%
Bioethanol	3%	0%	-2%
Hydrogen	0%	-13%	-26%

The third cost type that is taken into account is the so-called fuel procurement costs. Fuel procurement costs are mainly determined by the number of filling stations offering a certain fuel type. Table 5-2 shows the assumption on the development of filling stations that offer certain fuel types until 2040.

Table 5-2: Assumptions on Filling Stations offering Alternative Fuel Types in EU27+2

Fuel Type	Number of Filling Stations in EU27+2			
	2008	**2020**	**2030**	**2040**
Conventional	115,000	113,379	112,802	112,802
CNG	3,578	38,365	49,646	49,646
LPG	14,120	19,904	19,965	19,965
Electric	1,052	26,400	27,965	30,660
Bioethanol	2,171	26,603	34,659	34,659
Hydrogen	73	297	2,166	6,593

5.1.2 Baseline Scenario Results

This section provides trajectories for selected indicators from ASTRA-S for the baseline scenario until 2040. In order to explain the estimated trends of the baseline scenario, mainly indices and relative values are chosen for the presentation. The most suitable way to illustrate the trends of indicators across different fields is to use indices. Those indices are calculated relatively to the base year of 2008 and show the time path of an indicator from 2008 to 2040. Even if ASTRA-S allows detailed analysis on country-level, most indicators are presented in an aggregate way for all contemporary members of EU, the so-called EU27. In the following, only projections of GDP are presented in terms of average yearly growth rates per country.

5.1.2.1 Demographic Development

As opposed to all other ASTRA-S modules, the development of demographic indicators in the POP module is per definition independent from outputs of other modules. It is mainly based on exogenous data like fertility rates, death rates and migration balance. Only the new established household model is driven by GDP as only macroeconomic indicator. Hence, the depicted demographic development is valid for all scenarios. Nevertheless, population acts as one of the most significant drivers of economic, transport and environmental development. Thus, projections on demographic development in EU27 are relevant for the understanding of simulation results in all other ASTRA-S modules.

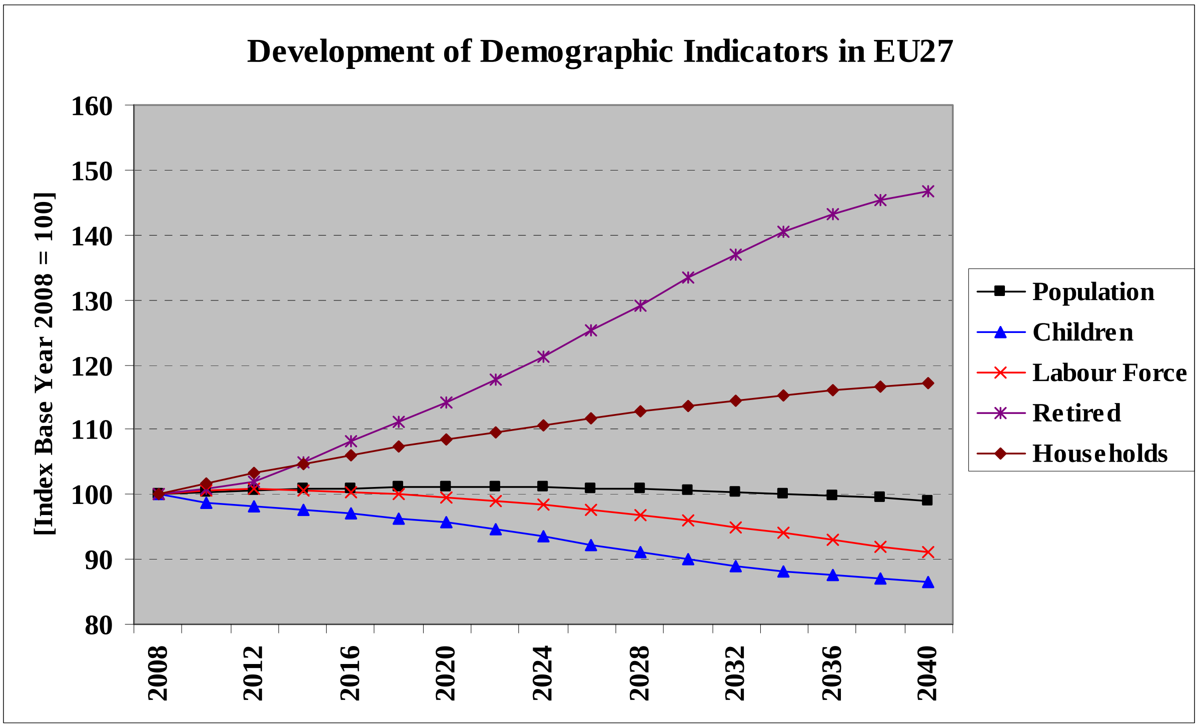

Figure 5-2: Demographic Trends in EU27 in BAU Scenario

Figure 5-2 provides an aggregated overview of population trends in EU27 countries until 2040. The stagnation or even small reduction of total population in EU27 of -0.97 % until 2040 compared with the base year 2008 indicates the trend that can be observed in most EU27 countries. Especially, Eastern European countries are affected by population decrease, while most Western European member states are characterised by a stagnating or even slightly growing population. Most of these countries lose population due to recent and prospectively expected high emigration rates compared with immigration. Additionally, most countries losing population suffer among the ageing society problem. Old vintages with high birth rates are in many countries already retired and finally more deaths compared with births lead to decreasing population. The growth of retired persons by +46.7 % with a simultaneous decline of children by –13.4 % and labour force by –8.8 % underlines the recrudescent problem of ageing society in EU27 until 2040.

The future development of another important trend of the past 18 years could be analysed by the integration of a household type model. Socio-economic drivers from the ASTRA-S POP and MAC module influence the development of household structure in EU27. Figure 5-3 shows the simulation results for all five household types considered in the ASTRA-S household model. Overall, the projections indicate that the total number of households in EU27 increases by +17.1 % until 2040. Regarding the decline of the EU27 population in the period from 1990 to 2040, this trend demonstrates that the average size of households decreases from 2.4 persons in 2008 to only 2 persons in 2040. The simulation results are characterised by significant growth of single households by +40.7 % and households of couples without children by +24.8 %. As in parallel the number of both households types with children, single parent and couples with children, is supposed to decrease by -9.2 % respectively -6.4 % until 2040, the trend to smaller and therefore more households becomes obvious.

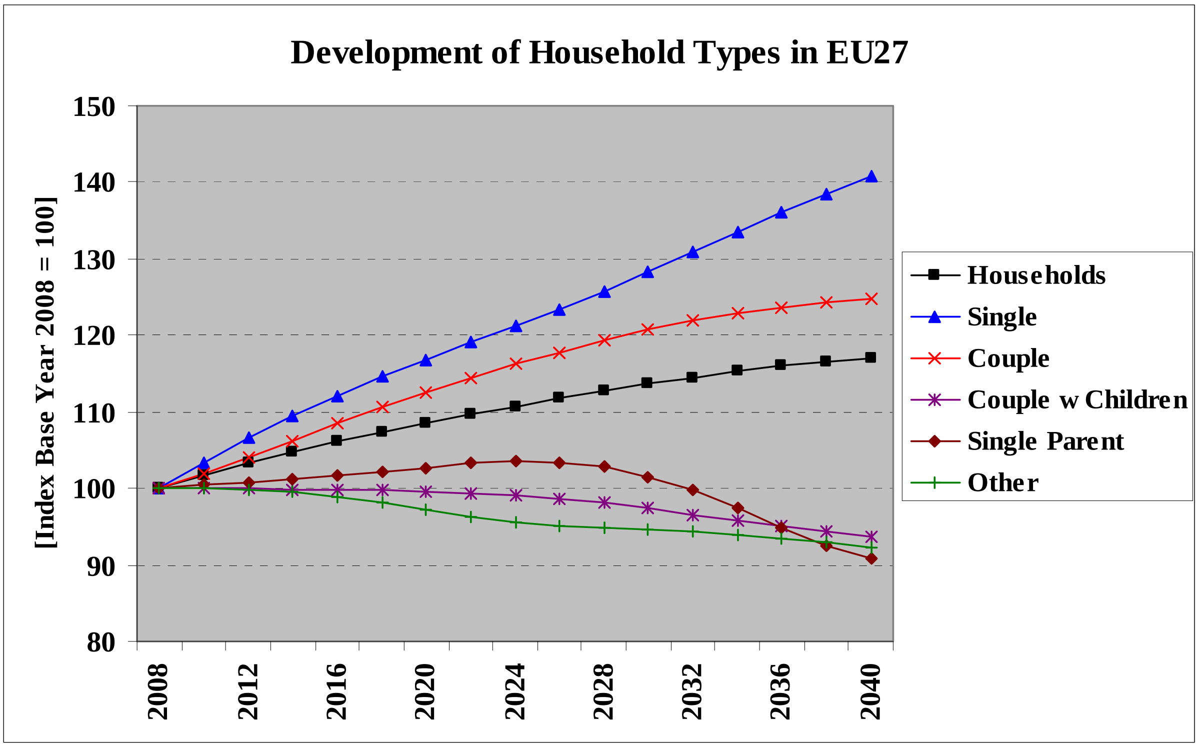

Figure 5-3: Development of Household Types in EU27 in BAU Scenario

In most EU27 countries the negative demographic trend and the arising burden on the national economies are major concerns. Policy-makers give high priority to family issues in order to stop the declining trend. Nevertheless, the results demonstrate that demographic development and especially the attempt of regulating demographic trends is a long-term process. Family-friendly policy which probably leads to higher birth rates impacts the economy only earliest decades later when young adults enter the labour market.

5.1.2.2 *Economic Development*

One of the major characteristics of the ASTRA-S MAC module is that economic development of the EU27+2 countries is calculated mainly endogenously. For example, GDP as most significant indicator for the measurement of economic development is derived from a number of causal relationships. Figure 5-4 pictures the simulation results of the most important economic indicators on aggregate EU27 level. GDP grows from the year 2008 by +54.8 % until 2040 in EU27. Transferred in average yearly growth rates in the period from 2008 to 2040 this would mean about +1.37 % growth of GDP. Consumption of private households follows nearly the same growth path, while exports and investments increase significantly stronger than GDP reaching +89.4 % for investments and +155.6 % for exports. This is equivalent to an annual growth of about +2 % for investments and +3 % for exports. The trajectory for total factor productivity (TFP) represents only an approximation. As this indicator is calculated on country level based on sectoral inputs, it is not possible to show an exact value for the EU27 as this involves some weighting process (while for GDP and the other previous monetary indicators the EU27 value can be added up across the 27 countries to get the EU27 value). The weighted indicator for TFP increases by +83.6 % until 2040. Gross capital increases by +95.7 % until 2040 and constitutes the most important contributor to growth of GDP on the supply side besides TFP. The only indicator stagnating over the whole time period is employment. A decline of -13.8 % can be observed for the indicator employment until 2040.

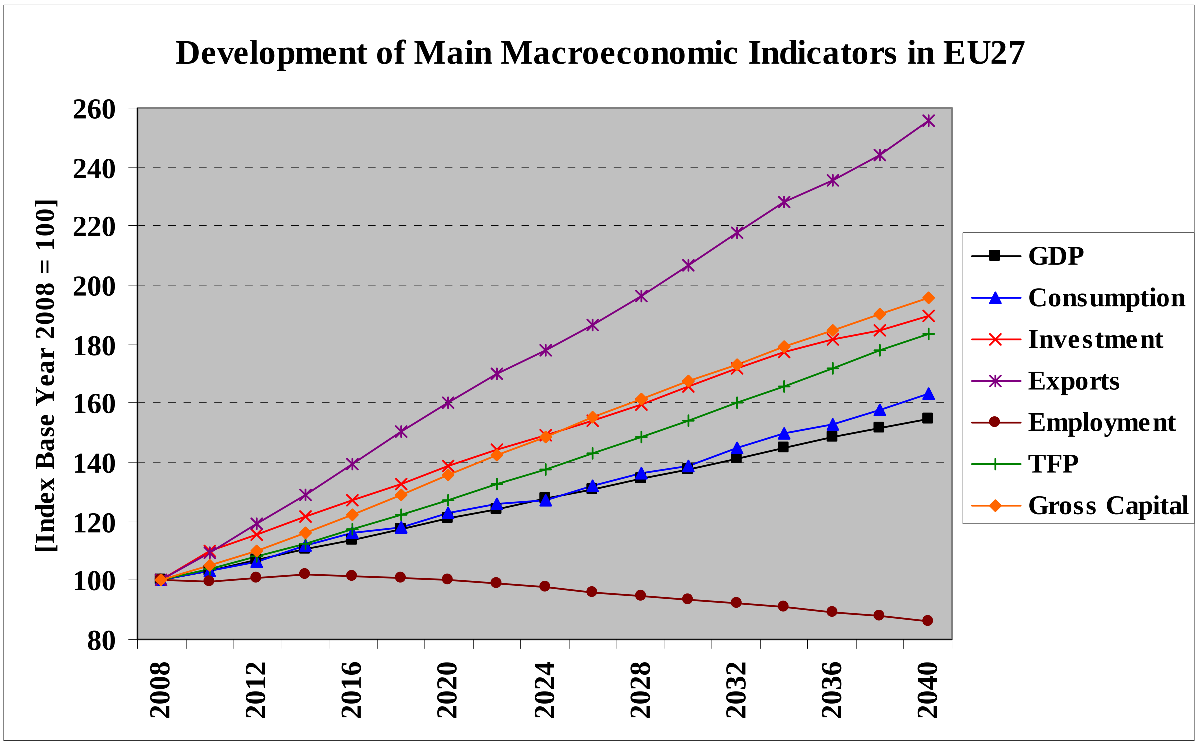

Figure 5-4: Macroeconomic Trends in EU27 in BAU Scenario

Having a closer look on GDP projections on country level (see Table 5-3) supports the understanding of the demonstrated rather small average yearly GDP growth rates in EU27. Countries contributing most to the absolute EU27 GDP value like Germany, France or Italy are estimated with low growth rates that fall at least in the period between 2020 and 2040 under 1 %. Generally, declining average yearly GDP growth rates can be observed in the period from 2020 to 2040 compared with the period from 2008 to 2020. UK, Denmark and the Netherlands denote the highest average yearly growth of GDP of +2 % respectively +1.9 % of the Western European countries, while Czech Republic, Latvia and Poland are outperforming by +3.8 % respectively +3.6 % in the Eastern European countries.

Table 5-3: Average Yearly GDP Growth Rate per Country

Country	2008-2040	2008-2020	2020-2040	Country	2008-2040	2008-2020	2020-2040
AUT	1.4 %	1.8 %	1.2 %	BLG	1.8 %	1.9 %	1.8 %
BLX	1.0 %	1.1 %	0.9 %	CHE	1.0 %	1.4 %	0.7 %
DNK	1.9 %	2.1 %	1.7 %	CYP	0.7 %	0.9 %	0.7 %
ESP	1.5 %	1.7 %	1.4 %	CZE	3.8 %	4.6 %	3.4 %
FIN	1.2 %	1.5 %	1.0 %	EST	1.3 %	1.5 %	1.2 %
FRA	0.3 %	0.6 %	0.2 %	HUN	1.9 %	2.4 %	1.6 %
GBR	2.0 %	2.1 %	1.9 %	LAT	3.6 %	3.9 %	3.4 %
GER	1.1 %	1.4 %	0.9 %	LTU	2.9 %	3.0 %	2.8 %
GRC	0.8 %	0.7 %	0.8 %	MLT	3.2 %	3.8 %	2.9 %
IRL	1.8 %	2.5 %	1.4 %	NOR	1.7 %	2.1 %	1.4 %
ITA	0.9 %	1.1 %	0.8 %	POL	3.6 %	4.2 %	3.2 %
NLD	1.9 %	2.3 %	1.7 %	ROM	3.3 %	3.6 %	3.1 %
PRT	1.7 %	2.1 %	1.5 %	SLO	2.2 %	3.0 %	1.7 %
SWE	1.5 %	1.8 %	1.3 %	SVK	2.2 %	2.5 %	2.0 %

The ASTRA-S model considers labour market trends as an important driver of income dynamics. Therefore, the development of employment per economic sector is highlighted in Table 5-4. As the total absolute number of employment declines mainly due to demographic changes, the sectoral employment trends are expressed in relative terms. Table 5-4 indicates the future importance of a certain sector regarding the share of employment per sector on total employment. The assumed fuel price development in the baseline scenario (see Figure 5-1) induces adaptation of industry and service sectors. Technological change in vehicle fleets influence the significance of the Vehicles sector which is reflected by higher share of employment in this sector in 2040 compared to 2008. Further sectors gaining significance in terms of employment are Energy, Computers, Food, Construction, Banking and Other Market Service sector. As opposed, Agriculture, Industrial Machines and the Non Market Service sector are losing importance in terms of employment.

Table 5-4: Share of Employment per Sector on Total Employment in EU27

Sector	2008	2020	2040	Sector	2008	2020	2040
Agriculture	7.2 %	6.1 %	5.8 %	Plastics	0.8 %	0.7 %	0.6 %
Energy	1.3 %	1.5 %	1.8 %	Other Manufacturing	1.0 %	0.9 %	0.7 %
Metals	0.5 %	0.5 %	0.5 %	Construction	8.5 %	9.3 %	9.4 %
Minerals	1.0 %	0.9 %	0.7 %	Trade	13.0 %	12.5 %	11.8 %
Chemicals	1.1 %	1.1 %	1.0 %	Catering	3.0 %	2.7 %	2.5 %
Metal Products	1.2 %	1.0 %	1.2 %	Transport Inland	2.3 %	2.1 %	2.1 %
Industrial Machines	2.7 %	2.4 %	1.8 %	Transport Air Maritime	0.6 %	0.6 %	0.7 %
Computers	0.9 %	1.1 %	1.2 %	Transport Auxiliary	0.9 %	0.9 %	0.9 %
Electronics	1.1 %	0.9 %	0.8 %	Communication	1.2 %	1.2 %	1.3 %
Vehicles	2.2 %	2.6 %	3.1 %	Banking	3.1 %	3.8 %	4.6 %
Food	2.2 %	2.2 %	2.5 %	Other Market Services	24.7 %	28.7 %	30.4 %
Textiles	2.7 %	2.5 %	2.7 %	Non Market Services	15.2 %	12.4 %	10.4 %
Paper	1.5 %	1.5 %	1.5 %				

The illustrated socio-economic results lead to the following picture of income distribution in EU27. Figure 5-5 presents indices for all five income groups aggregated over all EU27 countries. They reflect income mobility induced by socio-economic changes. Attention must be paid in the interpretation of income distribution simulation results. The ASTRA-S income distribution model considers all income types besides capital income. As comprehensive statements on future development of income inequality requires information of all income types, including capital income, the simulation results must be interpreted carefully. At first sight, Figure 5-5 does not unambiguously confirm recent trends of increasing income inequality in EU27 in the period between 2008 and 2040. From 2008 to 2015, a trend to positive income mobility is indicated by decreasing number of persons in the low income class (Low Inc), simultaneous significant expansion of the two highest income classes (High Inc and Med-High Inc) and slight increase of medium and low to medium income classes (Med Inc and Low-Med Inc). In the long term, the number of persons in both highest income classes decline by -25.7 % respectively -6.8 % compared with the base year 2008. In parallel, the Low-Med Inc and Low Inc classes gain by +26.7 % respectively +7.3 % while the number of persons in Med Inc class stagnates. To a great extent, the displayed results are influenced by demographic trends, like the growth of retired persons and decreasing number of labour force that go hand in hand in EU27. Additionally, labour market trends, like increasing unemployment and sectoral employment changes, contribute to the illustrated income distribution until 2040. Continuous transfer of employment from secondary to tertiary sector induces lower average incomes. This trend leads to higher frequency of income mobility into lower income classes.

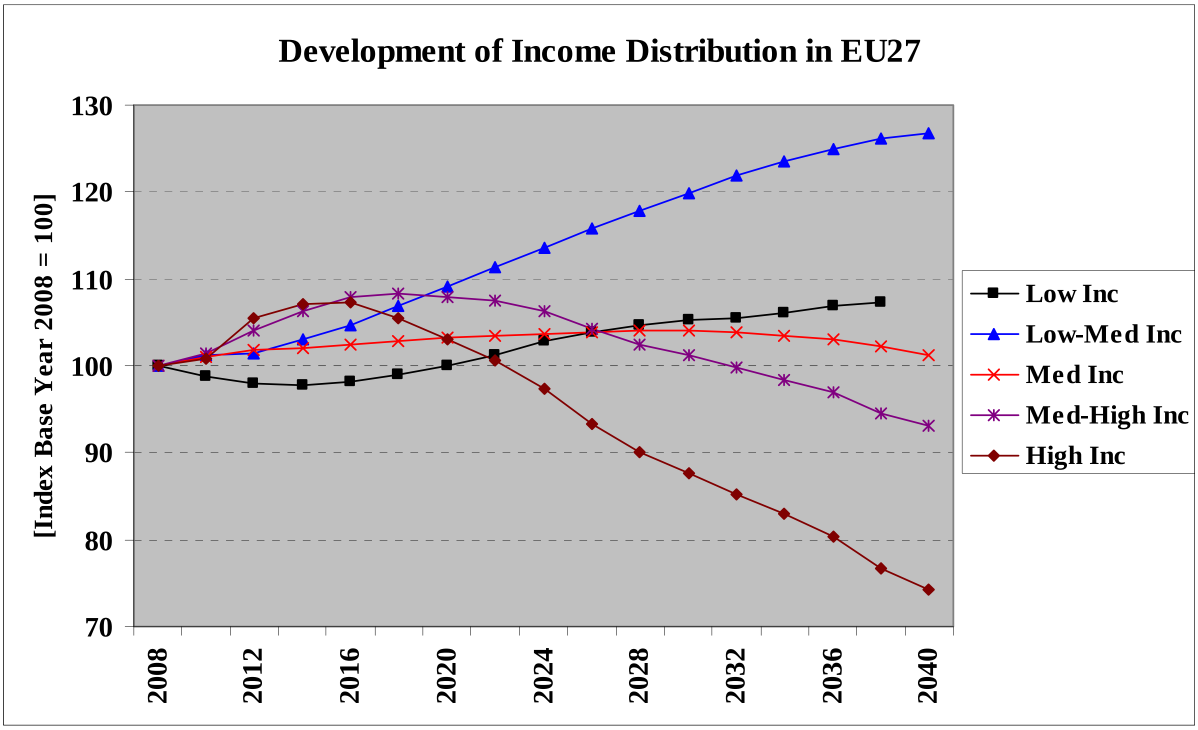

Figure 5-5: Income Distribution Trends in EU27 in BAU Scenario

5.1.2.3 Vehicle Fleet Development

Figure 5-6 provides an overview of the estimated vehicle fleet development in EU27 until 2040. Analysing the projections the different impact mechanisms for car, bus and goods vehicle fleets have to be taken into account. In contrast to new bus, light (LDV) and heavy duty vehicle (HDV) registrations, the number of passenger car purchases depends mainly on factors like demographic trends, development of average income, information on the distribution of income and variable and purchase costs. New registered buses are induced by growing demand in terms of passenger-km resulting from the modal split stage in the ASTRA-S TRA module. Monetary goods flows stemming from the FOT module and resulting physical goods flows impact the freight performance in terms of ton-km. Finally, this indicator is used to assess additionally required light and heavy duty vehicles.

The ASTRA car fleet model estimates a growth of EU27 passenger car fleet of +25.3 % until 2040 compared with the base year 2008. Spoken in absolute numbers, this means that the 27 member states of the EU will have 267 million registered cars until 2040. Hence, the car-ownership in EU27 increases continuously until 2040 and reaches a level of 549 cars per thousand inhabitants. The decline of passenger transport performance with buses leads to diminishing bus fleets by -24.7 % until 2040. Accelerating road freight transport causes growing demand for new goods vehicles. ASTRA-S estimates an increase of LDV and HDV fleets in the baseline scenario by +50.7 % respectively + 42.3 %.

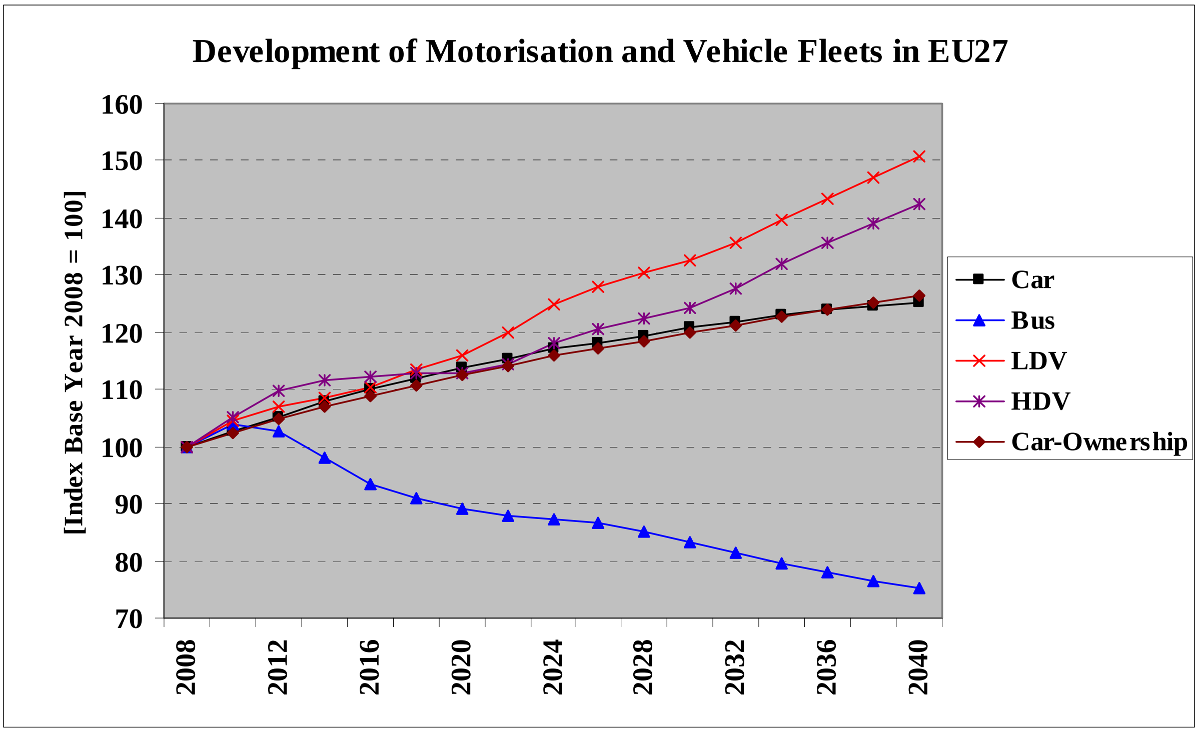

Figure 5-6: Development of Rolling Stock in EU27 in BAU Scenario

Considering the technological change of EU27 car fleets, the established technology choice model provides the following picture for the period between 2000 and 2040. Figure 5-7 shows the speed of diffusion of alternative fuel cars in car fleets of EU27 member states. According to the baseline scenario results, the share of alterative fuel cars on total number of registered cars in EU27 improves significantly from 3.4 % in the year 2010 to 26.5 % in the final simulation year 2040. The assumption of moderate mineral oil price development is mainly responsible for this rather pessimistic view on a future diffusion of alternative car technology.

The declining share of diesel and gasoline driven cars until 2040 indicates another interesting trend. Car purchasers that will decide to buy a conventional car will purchase significantly less high-motorised cars with large cubic capacities. In the year 2040, only 5.6 % of conventional cars will have more than 2.0 litre cubic capacity. The recent trend to high share of diesel car registrations disappears after the year 2010, due to high growth of diesel price.

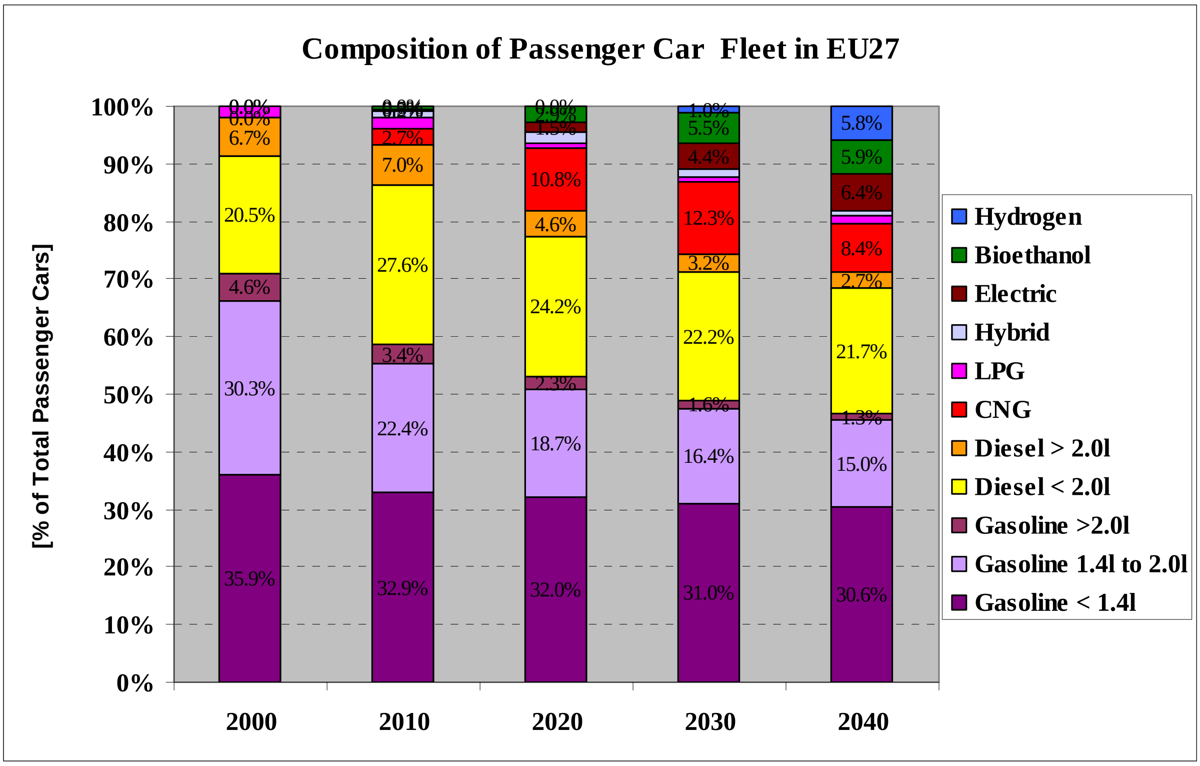

Figure 5-7: Technological Composition of EU27 Car Fleets in BAU Scenario

Despite high growth rates of CNG prices (displayed in Figure 5-1), CNG technology emerges as most important alternative car technology in the mid-term with a share of 12.3 % in the year 2030. Action plans of countries like Germany, Italy, Sweden, Austria and UK to support the diffusion of CNG cars into the markets via improvement of filling station infrastructure play an important role for this trend.

Recently reached milestones in the development of electric cars which improved the mileage and the time required to charge the battery lead to a positive trend until 2040 with 6.4 % share on total EU27 car fleet. Cars driven with bioethanol (E85) are projected to have an increasing market share reaching 5.9 % in 2040.

The prospective potential of hydrogen as future main fuel type can be derived from the development of its share from the year 2000 to 2040. While the ASTRA-S model estimates a small share of only 1 % in the year 2030, large numbers of car registrations with hydrogen technology lead to a final share of 5.9 % in 2040.

5.1.2.4 Transport Development

The trend of personal mobility shows a growth at different speed for old EU15 member states until 2004 and more recent EU member states since 2004. The latter are forecasted to increase faster in the near future as impact of higher income and motorisation growth rates. However, the expected decline of population in Eastern Europe partially compensates these determinants. Finally, the model estimates diminished growth rates until 2035 and even reduced mobility in absolute terms after the year 2035. Regarding the passenger transport performance on aggregate EU27 level, ASTRA-S projects a growth of passenger-km of

+12.5 % until 2040 (see Figure 5-8). Compared with +1.8 % average yearly growth of passenger-km in the recent years (CEC 2005), the baseline scenario of ASTRA-S forecasts with +0.4 % a slow down of personal mobility until 2040. The total number of trips generated with the help of socio-economic information provided by the NUTS2 population model and the income distribution model shows only a slight growth of +1.2 % until 2040. Hence, the major driver of passenger-km growth is the trend to increasing trip distances reflected in the ASTRA-S trip distribution model.

Besides aggregated passenger transport performance, Figure 5-8 illustrates as well the passenger modal split results. Due to moderate oil price growth in the baseline scenario, the indices for passenger-km per passenger transport mode show highest growth of air transport market. Air passenger-km are projected to rise by +32.2 %, car passenger-km by +14.1 % and train passenger-km by +12.1 % until 2040. Recent trends to decreasing bus passenger-km are confirmed by the ASTRA-S baseline results and a decrease of -19.4 % until 2040. Even if the baseline scenario considers only moderate growth of oil price, a reaction on individual mobility can be observed by +21.1 % growth of non-motorised passenger-km. Finally, ASTRA-S estimates a prospective modal share of air mode of 9.3 %, 8.8 % rail passenger-km, 6.5 % bus passenger-km, 71.3 % car passenger-km and 4 % share of non-motorised passenger-km.

The development of freight transport performance in terms of freight ton-km is mainly influenced by export activities simulated in the FOT module and national production values computed in the sectoral interchange model of the MAC module. According to the baseline scenario projections, ton-km will increase by +71 % until 2040.

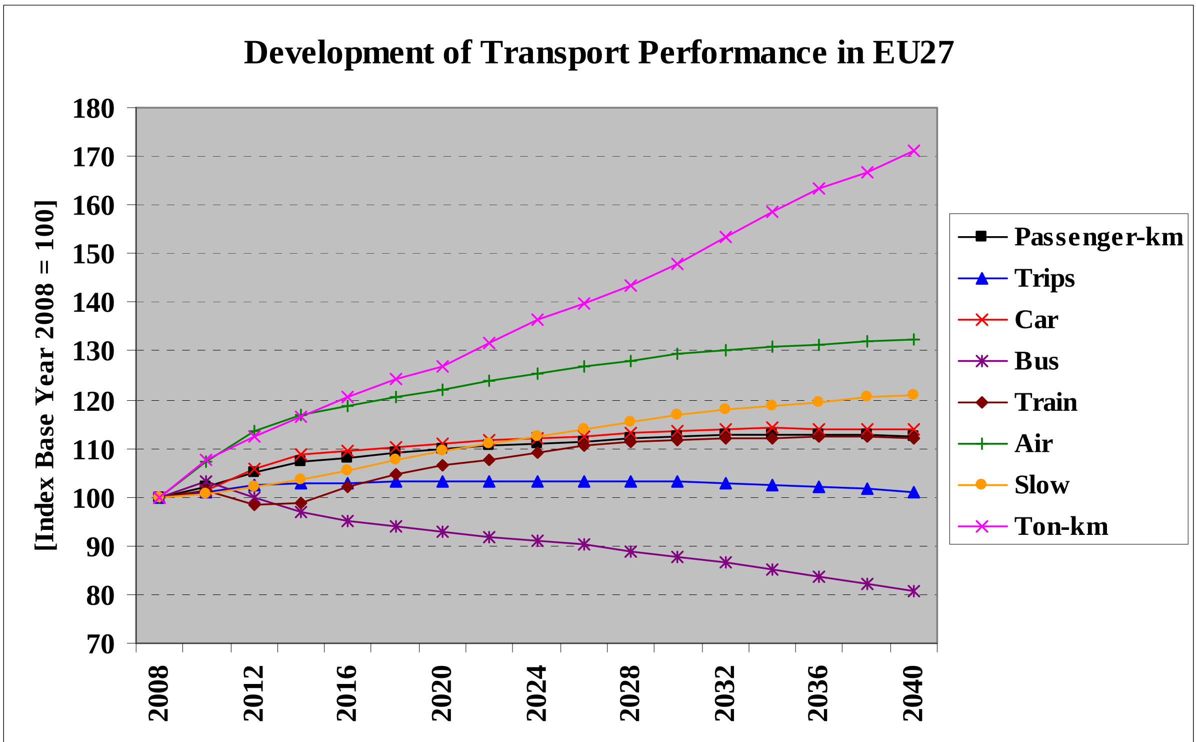

Figure 5-8: Transport Performance Trends in EU27 in BAU Scenario

5.1.2.5 Environmental Development

Based on the output of the TRA module and the differentiation of vehicle fleets into technologies and emission standards, the ASTRA-S model is able to estimate the resulting transport-related emissions. ASTRA-S considers emissions caused by combustion in engines as well as vehicle and fuel production emissions. Figure 5-9 demonstrates the environmental trends which are projected in the baseline scenario for this thesis. Stronger growth of passenger and freight transport performance together with high share of conventional diesel and gasoline cars in EU27 vehicle fleets lead to slightly growing transport-related CO_2 and CO emissions until the year 2015. In the long-term ASTRA-S forecasts emission reductions for all pollutants[20]. CO_2 emissions are estimated to decrease by -11.2 % until 2040 compared with the base year 2008. Considering the ASTRA-S projections until 2020, the CO_2 emission reduction plans determined by the European Commission are significantly off target.

Besides CO_2 emission reductions, the ASTRA model forecasts reductions of CO emissions by -4.2 %, NO_x emission reductions by -36.5 % and PM_{10} reductions by even -61 %. The technological improvements in the conventional car fleet are mainly responsible for NO_x and PM_{10} emission reductions. The only stagnating pollutants are the emissions of VOC. In the mid-term ASTRA-S approximates even growth of VOC emissions. The simulated increase of CNG cars in the EU27 car fleets is mainly responsible for this trend, as the combustion of CNG produces methane which is assigned to the group of VOC emissions.

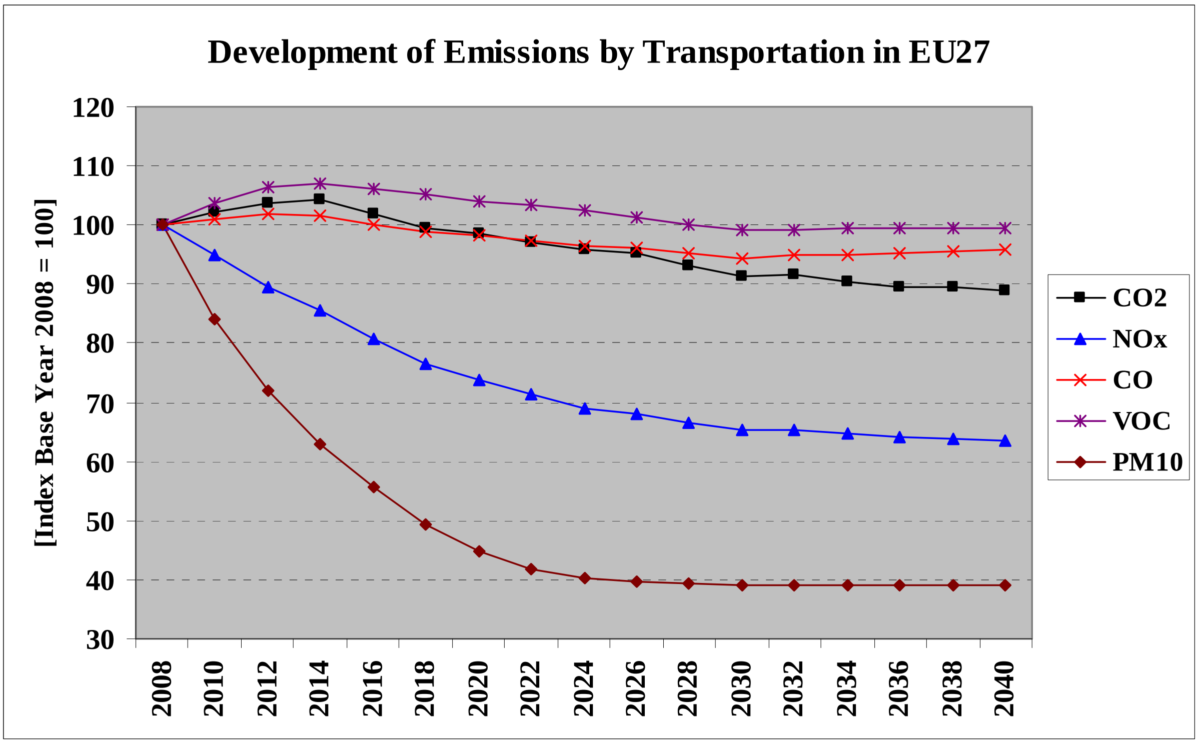

Figure 5-9: Development of Transport-Related Emissions in EU27 in BAU Scenario

[20] Actually CO_2 can not be denoted as a pollutant. For simplification reasons, the greenhouse gas CO_2 is allocated as well to the category of pollutants.

5.2 Comparison with Ex-Ante ASTRA Model

The main objective of this section is the analysis of income distribution impacts on trip generation and car registration. Therefore, a scenario is implemented which separates the new links between income distribution model and trip generation respectively car registration model. In this ex-ante scenario, the new links are substituted by the old links. Concerning the trip generation, this means that trips are determined by the number of persons in twelve population segments. Those population segments are differentiated by three age classes, two employment status and three car availabilities. The second link which is replaced with the ex-ante ASTRA version is the link that controls the development of new car registrations by considering upper motorisation limits per country. For the analysis of impacts, this endogenous constraint is switched to the exogenous constraint in the ex-ante ASTRA model.

As the difference between the baseline scenario for this thesis and the ex-ante scenario in absolute terms is not as expressive as the relative change compared to the ex-ante scenario, all impacts presented in this section are expressed in relative terms compared with the ex-ante scenario.

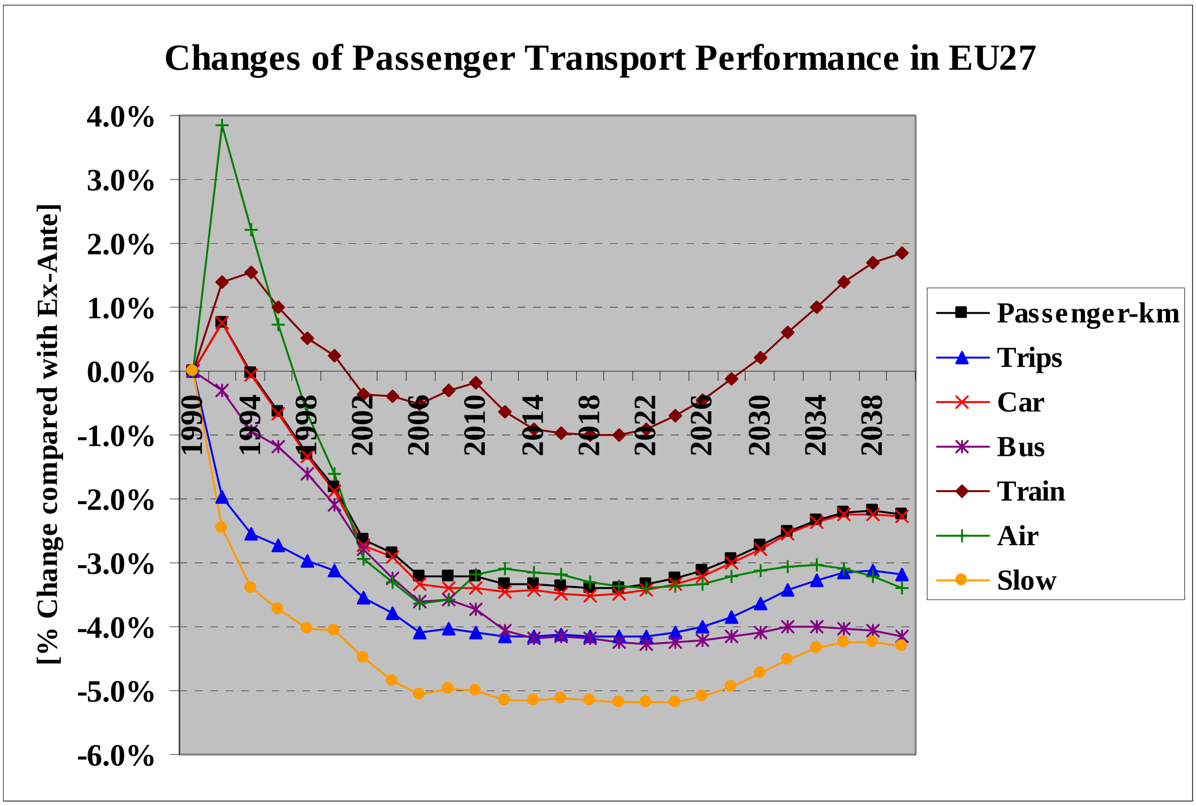

Figure 5-10: Comparison of Passenger Transport Performance with Ex-Ante ASTRA

Figure 5-10 presents the differences between the baseline scenario and the ex-ante scenario for the most important passenger transport performance indicators. As the trip generation model is modified for this thesis, the number of trips is directly affected by the switch to the ex-ante scenario. A significant difference between the total number of trips with consideration of income distribution impacts and more detailed differentiation into seven age classes and without consideration of income distribution can be observed in Figure 5-10. The total number of trips in the baseline scenario is up to –4.2 % smaller than in the ex-ante scenario.

As the deviation begins already in the calibration period from 1990 to 2005, several reasons can be responsible for the difference. The first could be an imprecise calibration of input factors in ASTRA-S like income distribution respectively population per age class. This reason can be excluded, as the calibration results were carefully checked concerning the deviation from the statistical values. The second possible reason might be the imprecise calibration of influencing factors in the ex-ante ASTRA model which can also be left aside as the calibration results are always under special observation. A third reason could be variations in the resulting trip rates derived from travel surveys. As the trip rates are differentiated on the one hand into person clusters determined by income and age classes and on the other hand into person clusters containing information about the employment status, age class and car availability, the trip rates can not be compared. The most plausible reason might be the significance of a chosen allocation of persons into segments according to combination of attributes. As the significance of the chosen attributes is analysed within a variance analysis in chapter 4.4.2.2, the resulting number of trips in the baseline scenario can be considered as valid.

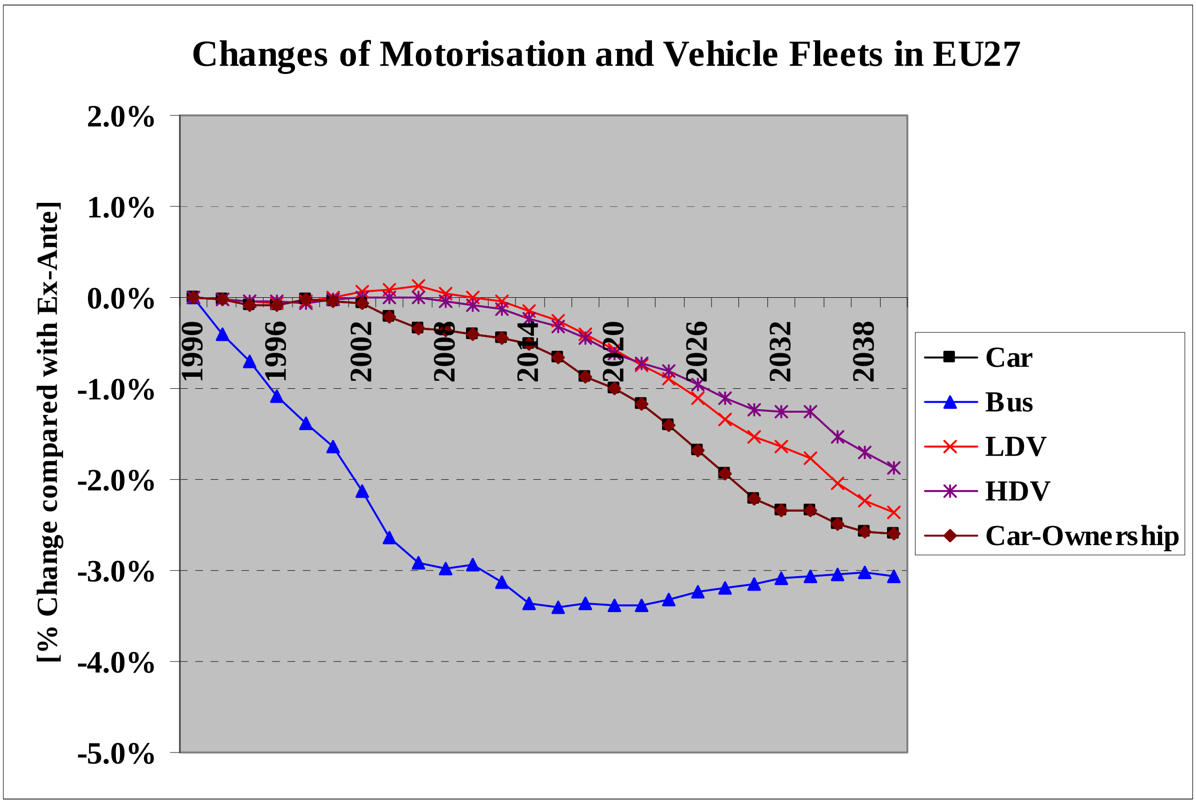

Figure 5-11: Comparison of Vehicle Fleets with Ex-Ante ASTRA

The illustrated change of passenger-km up to -3.4 % compared with the ex-ante scenario can be assigned mainly to the difference in total number of trips generated in the first stage of the four-stage transport model. Additionally, the new link from income distribution to car registration plays an important role. Results of the ex-ante ASTRA model demonstrate that the exogenous constraint allowed implausible motorisation numbers of up to thousand cars per thousand inhabitants. The new income distribution model controls the upper limit in a way that more realistic motorisation numbers could be simulated. Figure 5-11 reflects a decrease of car-ownership by -2.6 % in the baseline scenario compared with the ex-ante scenario. The resulting changes in bus, LDV and HDV fleets are mainly induced by changing passenger and freight transport performance.

The latter change can not be assigned to direct impacts of integration of income distribution. Less car registrations and lower number of trip rates are responsible for lower growth of major macroeconomic indicators. Figure 5-12 highlights the differences initiated by the integration of income distribution inputs in the trip generation and car registration model. Compared with the ex-ante scenario, GDP in the baseline scenario is by -2.9 % lower. The main drivers for this change are decreasing investments and consumption caused by less car purchases and diminished passenger transport performance.

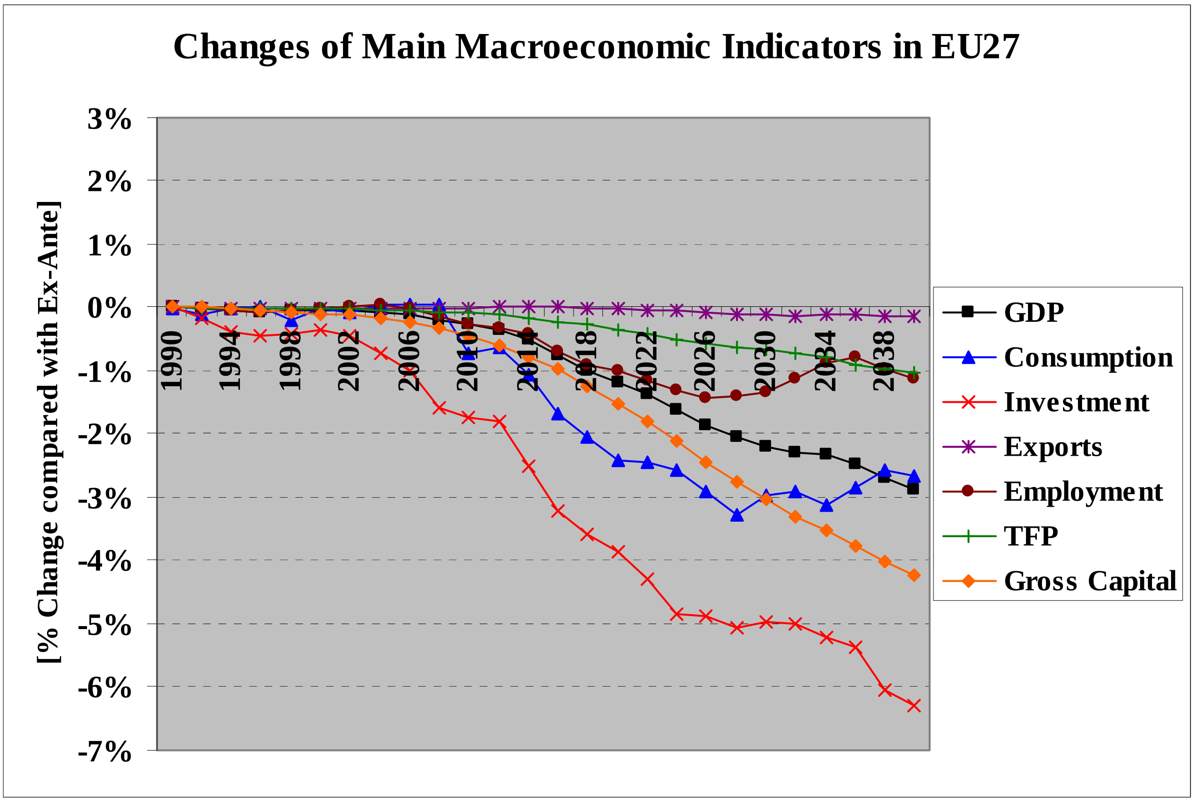

Figure 5-12: Comparison of Main Macroeconomic Indicators with Ex-Ante ASTRA

As the composition of car fleets is influenced only marginally by the integration of income distribution, smaller growth of passenger and freight transport are mainly responsible for the resulting changes of transport-related emissions displayed in Figure 5-13. The baseline scenario computes -1.2 % CO_2, -3.3 % NO_x, -4.4 % CO and - 4.6 % VOC emissions until 2040, compared with the ex-ante scenario.

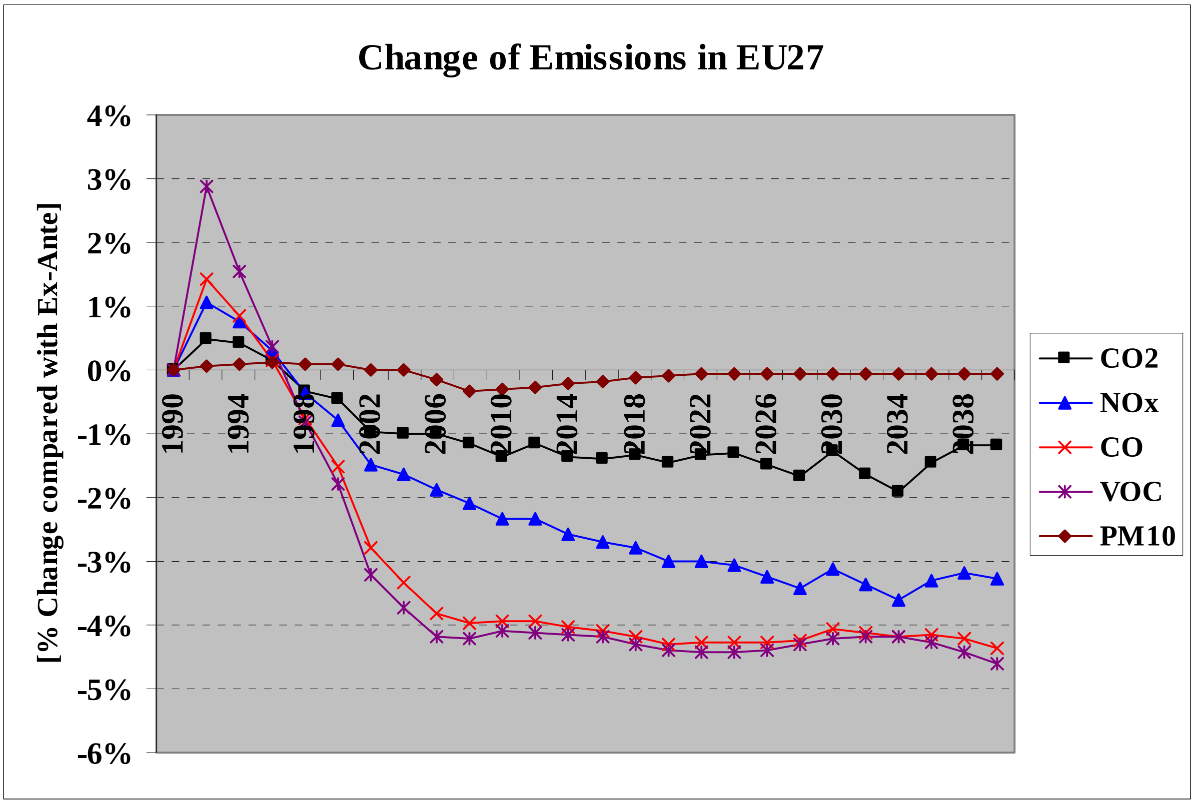

Figure 5-13: Comparison of Transport-Related Emissions with Ex-Ante ASTRA

5.3 Policy Scenario

Shai Agassi, the founder of "Project Better Place"[21] stated the following hypothesis: *"Doing the right thing for the environment can be the best thing for business"* (AGASSI 2008). ASTRA-S as an integrated macroeconomic, transport and environment System Dynamics model is able to prove or disprove the validity of this thesis for a variety of scenarios. Several studies which have been carried out with ASTRA, e.g. SCHADE ET AL. (2008), could confirm this hypothesis for a variety of realistic future scenarios with its simulation results. In the following the impacts of a scenario will be tested which has the potential to reduce transport-related emissions as well as support economic growth in EU27.

The main objective of this section is the presentation of the impact assessment results of a combined policy and technology scenario. In order to demonstrate the capabilities of the ASTRA-S model and especially the new established car technology model, a scenario has been chosen which foresees policy actions to support hydrogen as future clean energy source for transport. As ASTRA-S considers not only the technological impacts of these policy actions, the necessary expenditures can be simulated as well. The funding of subsidies for an acceleration of hydrogen car diffusion into EU27 car fleets is implemented via a carbon tax which will be introduced in the year 2010. In the following, a detailed definition of the implemented scenario will be presented. Finally, the simulation results will be depicted and analysed.

[21] "Better Place" is a venture-backed company that aims to reduce global dependency on oil through the creation of a market-based transportation infrastructure that supports electric vehicles, providing consumers with a cleaner, sustainable, personal transportation alternative.

5.3.1 Policy Scenario Definition

The scenario which is analysed in this thesis consists of an introduction of a carbon tax for all considered types of fuels. Hence, the tax is considered not only on conventional fuels but also on hydrogen and bioethanol. A constant carbon tax level of 50 Euro per ton in real terms is introduced in the year 2009. This tax level extends the carbon tax level of 30 Euro per ton which is derived from a study that assumes a 21 % domestic reduction of greenhouse gas emissions in EU27 until 2020 (JRC et al. 2007). As this thesis focuses mainly on passenger transport, the carbon tax is implemented for passenger transport excluding only air transport. Furthermore, shippers might argue that a further financial burden of a carbon tax on top of tolls would threat their companies due to higher transport costs.

The implemented policy scenario assumes the application of carbon tax revenues for supporting hydrogen as future clean energy source for passenger cars. Therefore, the policy scenario is named *H_2 scenario* in the following. The main objective of all policy actions implemented in this scenario is the improvement of competitiveness of hydrogen technology. Therefore, total amount of yearly carbon tax revenues which decreases from about 37 billion Euro in the year 2010 to 20 billion Euro in the year 2040 is allocated to different policy actions.

The first action concerns the support of hydrogen infrastructure development which enables mass production of fuel under the constraint of lowest possible emissions. TORO ET AL. (2006) estimated well-to-wheel costs for all available hydrogen production pathways until 2050. In order to support clean production of hydrogen and to ensure the supply of hydrogen, about 4 billion Euro per year are invested. Another important factor is the H_2 price at the filling station. The H_2 scenario assumes that investment in production plants lead to H_2 price reductions up to 20 % compared with the baseline scenario. The H_2 scenario prerequisites a realisation of the H_2 price reduction until the year 2020.

Furthermore, the revenues are applied to accelerate the installation of a sufficient filling station network in EU27+2 countries. In the baseline scenario the development of filling stations offering H_2 fuel, is estimated by about 6,500 filling stations in EU27+2 until 2040. According to the remaining yearly revenues from carbon tax, the number of filling stations in the H_2 scenario nearly doubles and reaches a level of 12,500 filling stations in the year 2040. Regarding the complex technology required for supplying filling stations for H_2, a large share of the carbon tax revenues must be invested in this support action.

Concerning the subsidising of hydrogen car prices (fuel cell, internal combustion H_2 and hybrid H_2) only a small share of the carbon tax revenues has to be invested, as the growing demand caused by increasing competitiveness will lead to significant reduction of car prices. Only in the first years, a subsidy is required, when the sale numbers of car manufacturers reach only a low level. Finally, about 25 % price reduction can be achieved until 2040 compared with the baseline scenario.

5.3.2 Policy Scenario Results

The main results of the H_2 scenario are presented in this chapter. For a better overview and interpretation of results, nearly all results are depicted as relative changes compared to the baseline scenario (BAU). Similar to the baseline scenario, the results are shown in a sequence for all impacted ASTRA-S modules.

In order to classify the dimension of an introduction of a carbon tax at the level of 50 Euro per ton in real terms, the carbon tax is transferred into amount per vehicle-km for all vehicle categories. Additional costs caused by carbon tax vary between 1.1 Eurocent per vehicle-km for average small gasoline cars up to 2.7 Eurocent for diesel cars with more than 2 litre cubic capacity. Average LPG cars are charged with 2.4 Eurocent per vehicle-km. Drivers of CNG cars have to pay on average 0.9 Eurocent, hybrid car drivers 1 Eurocent and cars with bioethanol engines are burdened by only 0.3 Eurocent per vehicle-km. In comparison with total average car costs per vehicle-km of 30 to 60 Eurocents, the additional burden caused by the carbon tax can be considered as just and reasonable.

Bus companies have to face on average 15.3 Eurocent while rail companies have to account 30.9 Eurocent per vehicle-km additional costs caused by the introduction of a carbon tax. The H_2 scenario considers in the case of price increases due to a carbon tax that bus companies as well as rail companies pass the additional burden to 100 % to the customer.

The understanding of major feedback mechanisms influenced by the policy actions and assumptions of the H_2 scenario is useful concerning a proper interpretation of scenario results. Figure 5-14 gives an overview of the most important interactions and feedback mechanisms for the H_2 scenario. In order to demonstrate one of the simulated impacts of the H_2 scenario in the ASTRA-S model, one causal loop is exemplified in the following figure.

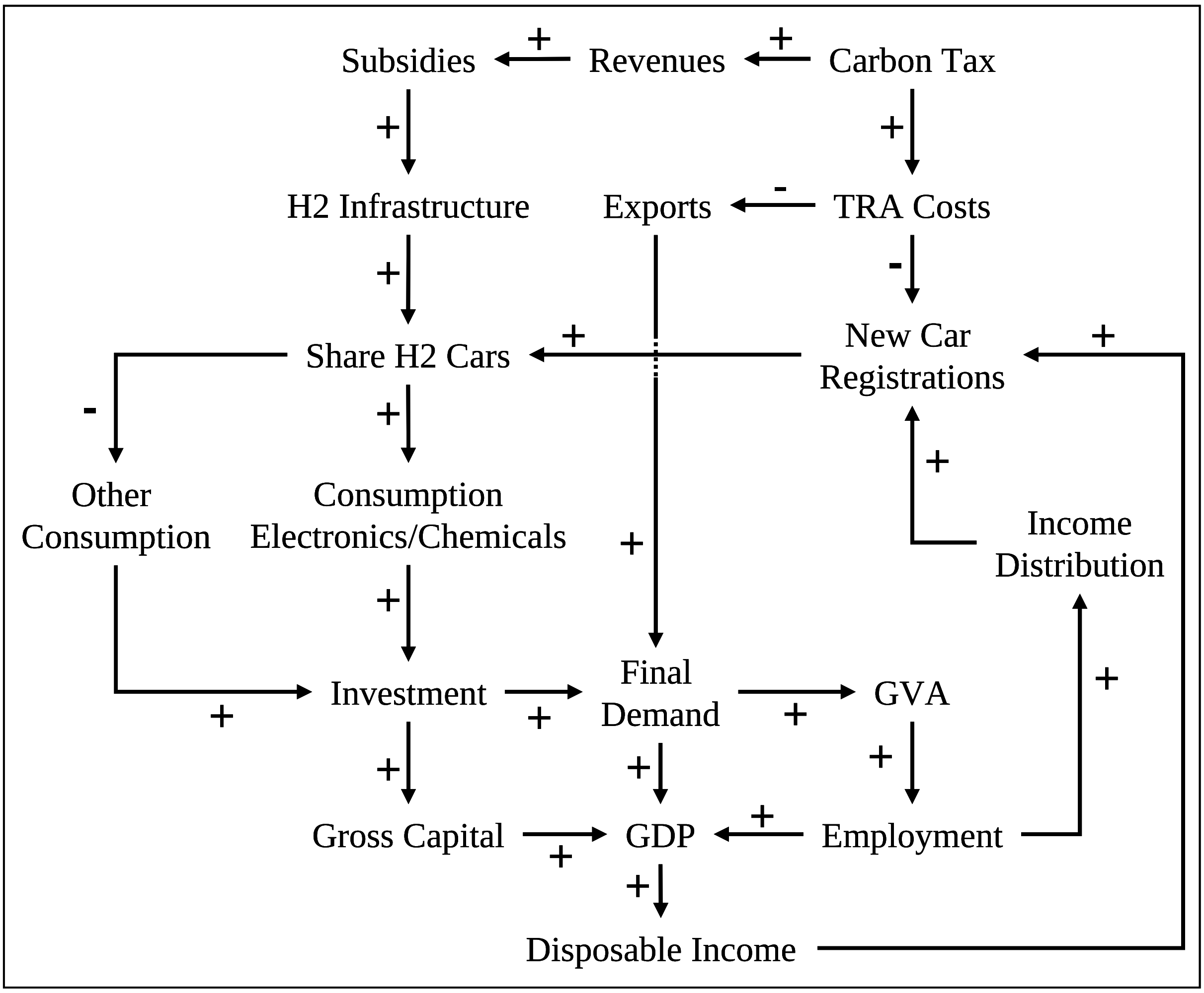

Figure 5-14: Major Feedback Loops Determining H2 Scenario Results

The assumed application of revenues for new H_2 filling stations reduce the fuel procurement costs and lead to increasing attractiveness of hydrogen technology for car purchasers. With increasing sales of H_2 cars, the sectoral consumption structure changes as H_2 car technology is assigned to chemicals, electronics and vehicle production sector. The increment of consumption in these sectors induces further investments in production plants which finally pushes GDP growth rates. Growing GDP yield via national accounting framework to increasing disposable income of private households. The development of disposable income is one of the major drivers of car registration. Finally, the feedback loop is closed when the higher share of H_2 cars in total registrations is combined with overall increase of new car registrations.

One of the most interesting questions that can be answered by the simulation results is if the diffusion of H_2 cars into EU27 car fleets can be accelerated significantly by the policy actions in the H_2 scenario. Figure 5-16 gives an explicit idea of the prospective technological development evoked by the mechanisms of the H_2 scenario. ASTRA-S confirms significantly increasing competitiveness and attractiveness of H_2 cars by a growth of the share of H_2 cars of about +19 % until 2040. The time required for installing an efficient hydrogen industry that can produce H_2 fuel for a competitive price and for the adjustment process of car industry can be observed in Figure 5-16. After the year 2020, the demand for cars equipped with hydrogen technology is estimated to grow significantly. Especially small conventional car registrations are substituted by the hydrogen technology. According to the ASTRA-S projections, the smallest gasoline and diesel car category lose a share of each -5.6 % compared with the baseline scenario. This projection indicates that consumers with smaller budgets are supposed to act more rational than higher income groups.

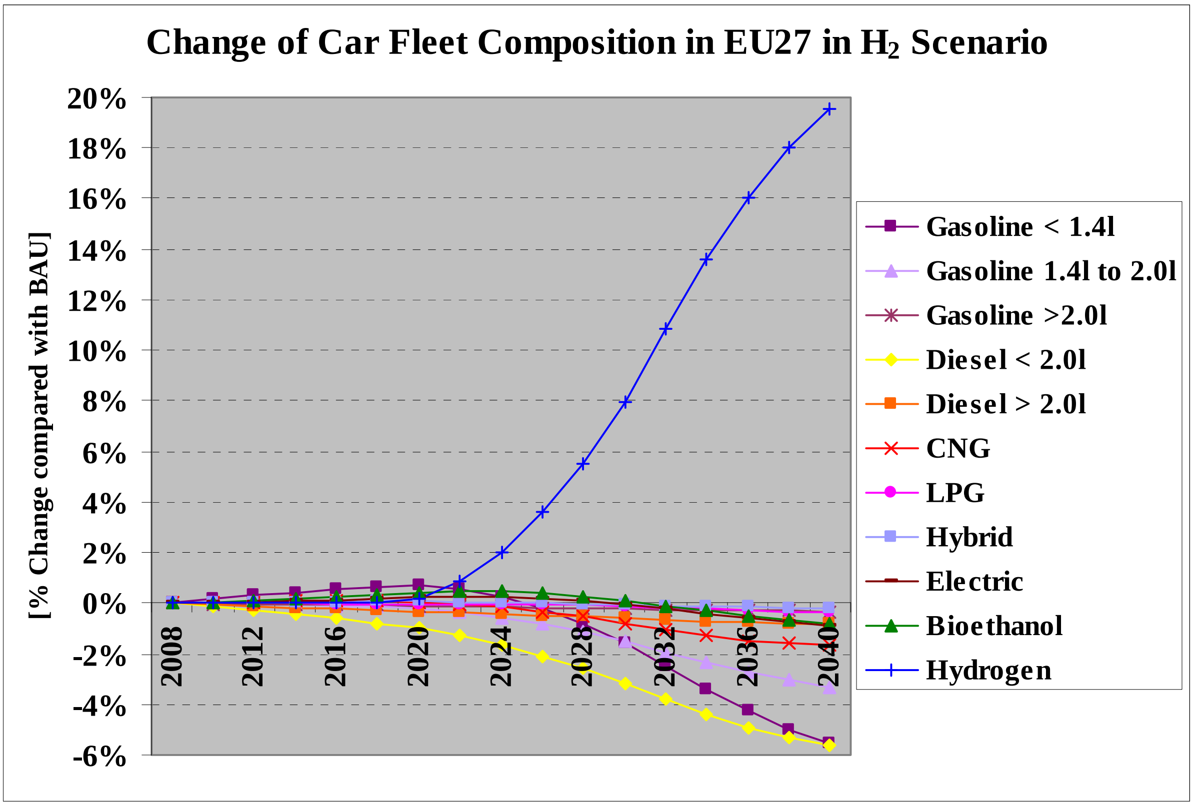

Figure 5-15: Change of Car Fleet Composition in EU27 in H_2 Scenario

Before H_2 cars reach the level of readiness for marketing, bioethanol, hybrid and CNG car sales are forecasted to increase slightly due to lower carbon tax burdens. Regarding the final composition of car fleets in EU27 in the year 2040 (see Figure 5-16), hydrogen cars provide the second highest technology with 25.4 %. The share of cars with conventional technologies decreases from 93.3 % in the year 2010 to 55.6 % in the year 2040. The simulation results show that electric, bioethanol and CNG cars reach a small share of 5.1 % to 6.7 % until 2040.

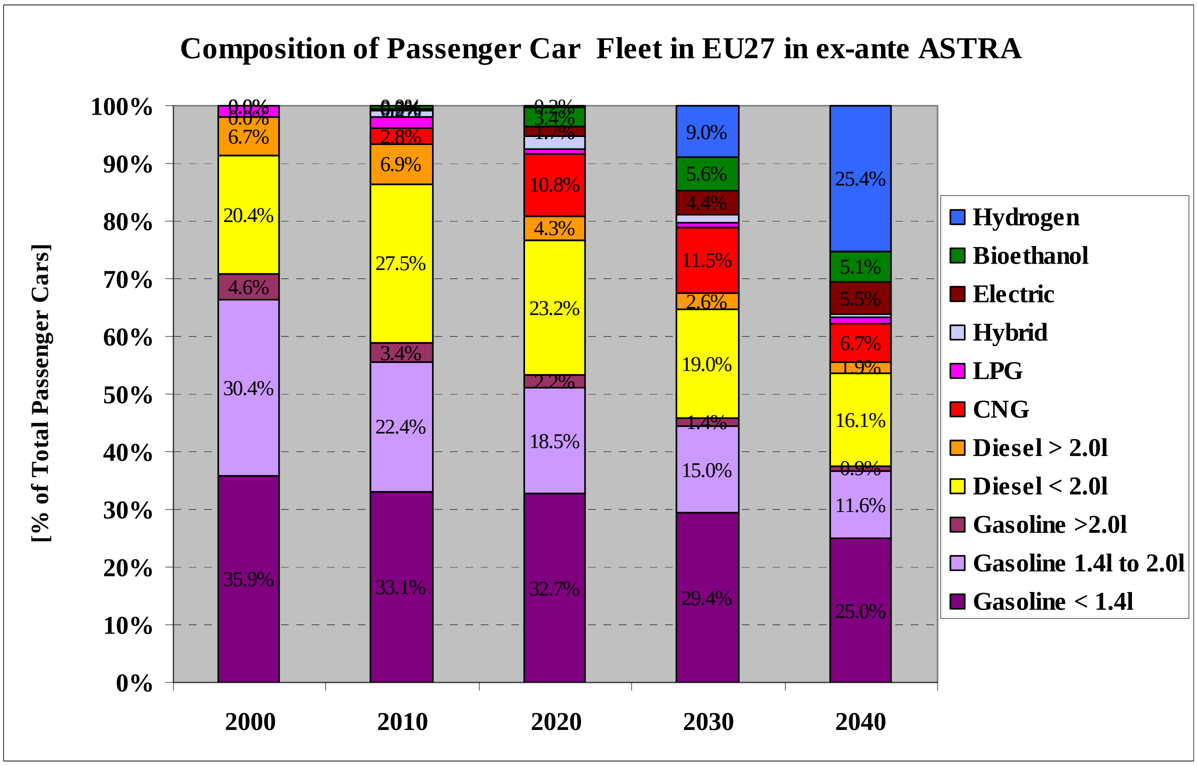

Figure 5-16: Technological Composition of Car Fleets in EU27 in H_2 Scenario

Figure 5-17 reflects the macroeconomic impacts of the introduction of a carbon tax and parallel investments into hydrogen infrastructure. All indicators besides exports are significantly influenced in a positive way compared with the baseline scenario. The financial support for investments in hydrogen production plants and filling station network pushes the economy in EU27. ASTRA-S projects a growth of investments by +6.7 % compared with the baseline scenario. Besides exogenous investments in hydrogen technology, endogenous feedback mechanisms contribute to the depicted growth of investments in EU27. Even if the carbon tax increases transport costs only marginally, the ASTRA-S model forecasts reactions of costumers on the additional financial burden and the rising attractiveness of hydrogen cars. This reaction can be observed in a growth of consumption by +3.4 % compared with the baseline case until 2040. Nevertheless, negative impacts can be observed as well. Increasing transport costs let exports stagnate compared with the baseline scenario. Overall, final demand in the H_2 scenario is estimated to grow which influences the sectoral interchange model. Technological change and increment of final demand lead to changes in gross value-added. Finally, this effects significant changes at labour markets in EU27. ASTRA-S forecasts an increase of employment by +1.7 % compared with the baseline scenario.

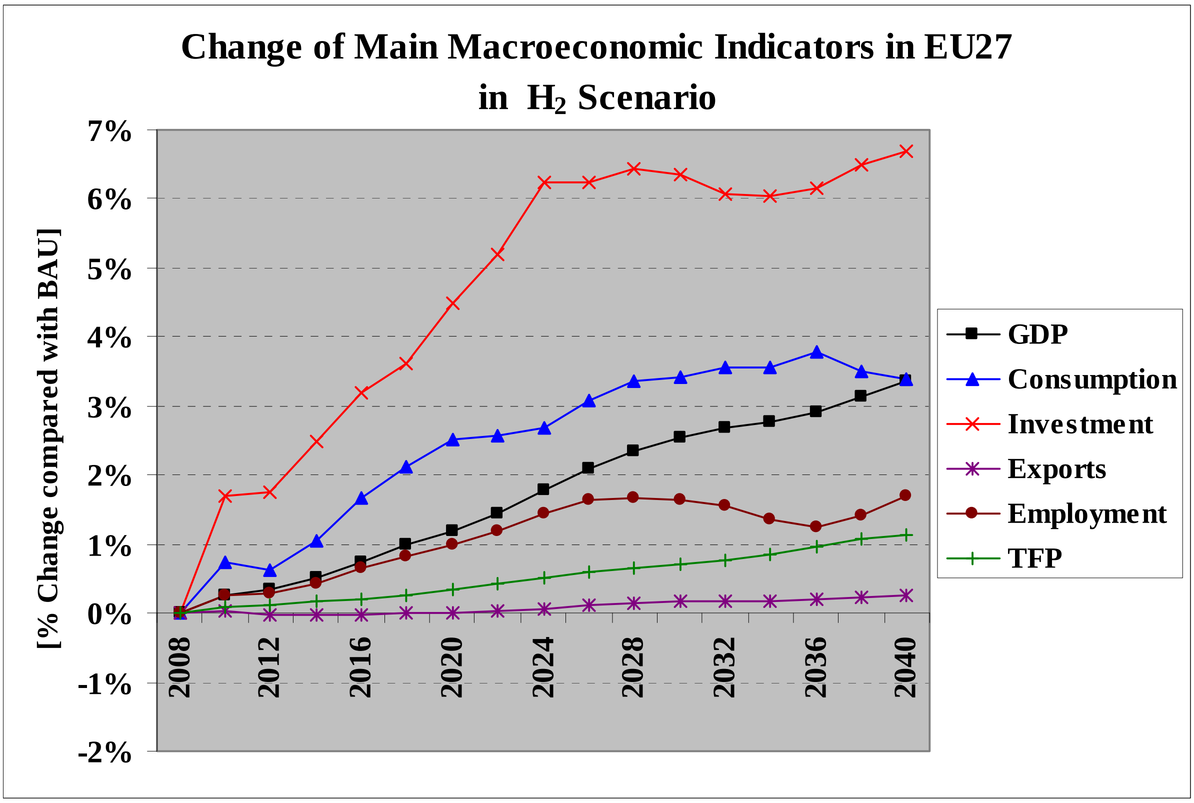

Figure 5-17: Change of Main Macroeconomic Indicators in EU27 in H_2 Scenario

The development of income distribution, illustrated in Figure 5-18, reflects the positive macroeconomic trends caused by the H_2 scenario. Positive changes on EU27 labour markets and a new push for industry sectors like Chemicals, Electronics and Vehicles sector initiate income mobility in higher income classes. The number of persons in the income classes with low and low to medium income decline, while in parallel the medium and high income classes gain persons. After a stagnation of investments in the year 2025 compared with the baseline scenario and interrupted positive employment trend, the income distribution shows a decline of persons in the highest income class. Nevertheless, still more persons belong to the high income class until 2040 than in the baseline scenario.

The presented income distribution trend influences two other ASTRA-S indicators. The first influence concerns the number of car registrations. Increasing average disposable income together with income mobility into higher income classes impacts about +2.9 % growth of motorisation compared with the baseline scenario. Growing registration numbers impact again the development of investments. Secondly, the change of motorisation influences the modal share in the passenger modal split model. The more car-owners exist, the higher becomes the modal share of car mode.

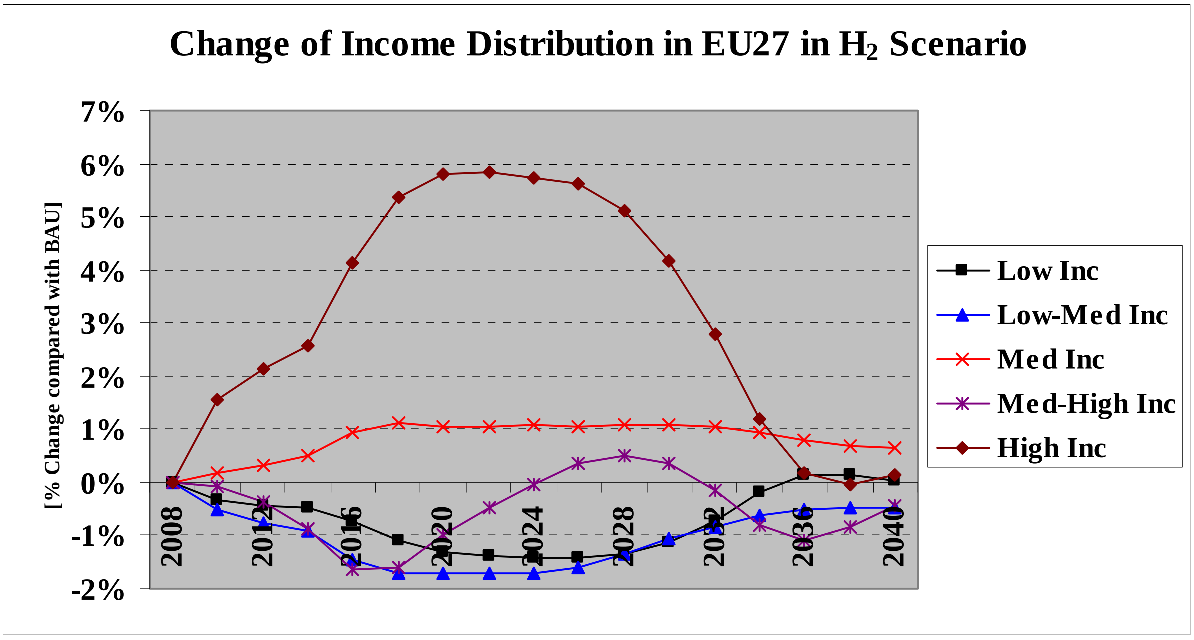

Figure 5-18: Change of Income Distribution in EU27 in H_2 Scenario

The second impact of income distribution can be observed in the changes of passenger transport performance. Figure 5-19 indicates a growing number of trips in EU27 in the H_2 scenario. The growth of trips by +3.6 % is mainly caused by positive income mobility, as persons in higher income classes are characterised by higher mobility. This coherence has been identified in the course of travel survey analysis and the calculation of trip rates per population segment.

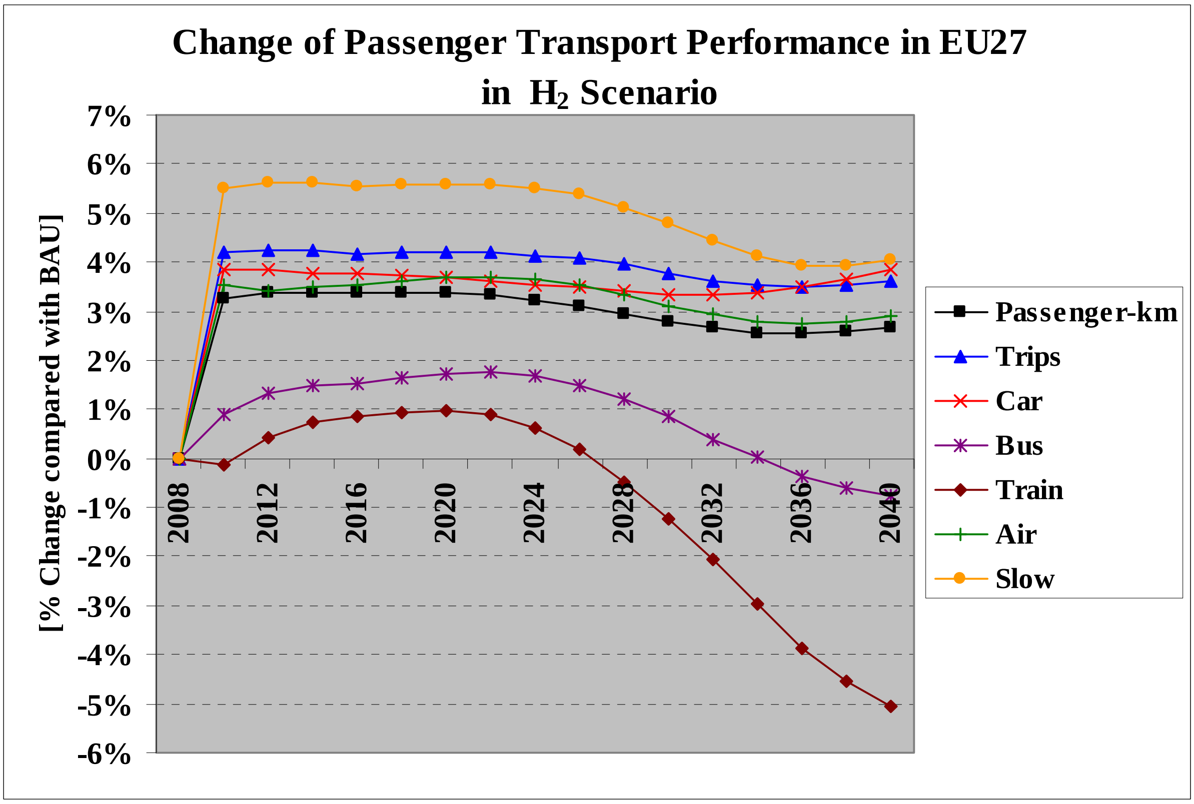

Figure 5-19: Change of Passenger Transport Performance in EU27 in H_2 Scenario

The trip growth is reflected in all other transport performance indicators. The relative development of passenger-km per mode follows the direction of the trip trends. The highest increment of passenger-km is projected for the slow mode, containing trips by bike or foot. At first sight the positive change of passenger-km by car seems to be astonishing. Taking into account the growing car availability, this trend can be reasonably explained.

Positive changes in passenger transport performance compensate at least partially the technological improvements in the car technology regarding greenhouse gases. Even if ASTRA-S projections for the H2 scenario reflect reductions of CO_2 emissions by -7 %, CO and NO_x emissions increase by about +3 % due to growing car passenger-km and especially ton-km. Positive economic trends are responsible for freight transport growth which, in contrast to passenger transport, is not charged by the carbon tax.

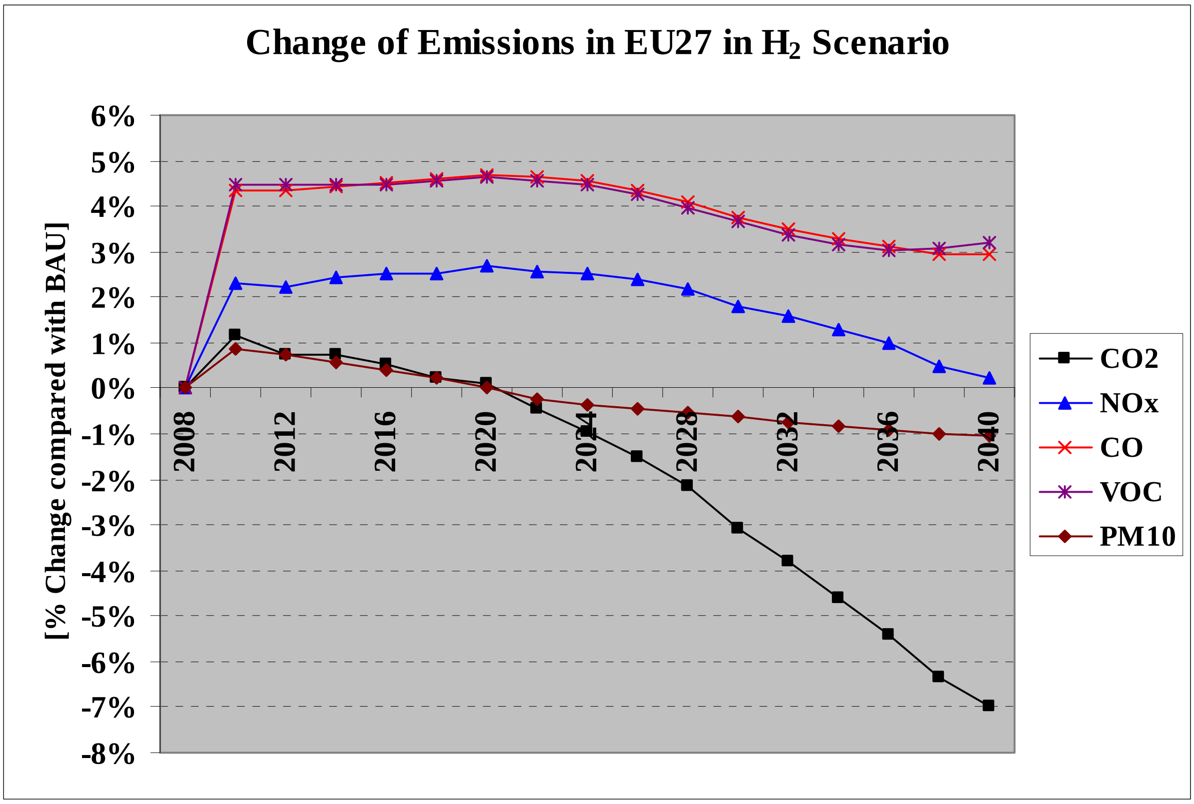

Figure 5-20: Change of Transport-Related Emissions in EU27 in H_2 Scenario

6 Conclusion and Outlook

6.1 Conclusion

The main objective of this thesis consists in the system-based analysis of income distribution impacts on passenger trip-making behaviour. In order to enable this analysis, a concept is drawn which foresees as first step the development and integration of an income distribution model into the ASTRA model. Requirements on the structure and the output of the income distribution model are derived from the needs of the models which are supposed to be influenced directly by the income distribution model: the passenger trip generation model which is a sub-model of the ASTRA-S Regional Economics (REM) and Transport (TRA) module, and the car registration model which is embedded in the ASTRA-S Vehicle Fleet (VFT) module. Under the constraint of available socio-economic data the income distribution model is designed and implemented in the ASTRA-S Macroeconomic (MAC) module. Income distribution into five income classes in ASTRA-S is assumed to be mainly driven by endogenous indicators of other ASTRA-S sub-models. After the parameterisation which is determined in the course of the model calibration the observed progress of income distribution in European socio-economic panels between 1990 and 2004 can be simulated with the new income distribution model with only small deviations.

In the course of analysis of European travel surveys, all those surveys can be excluded from further comprehensive analysis of mobility behaviour of persons in different income groups which did not query income as a significant attribute influencing trip-making behaviour. Finally, the German Mobility Panel (MOP) has been analysed in detail. In the course of this analysis, a classification of personal attributes is carried out to identify further significant personal attributes concerning their explanatory power on trip-making behaviour. After the determination of age classes as second attribute, the average number of trips per population segment is extracted from the MOP databases of the years 2002 to 2006. According this analysis, persons with low income are assumed to be by -10 % up to -12 % less mobile in terms of yearly trip numbers compared with persons in medium income class. The British National Travel Survey confirms this trend. In Britain even about -24 % less trips are made by persons in the lowest income class. Finally, all findings are implemented in the ASTRA-S trip generation model.

In order to avoid overestimation of prospective motorisation in European countries, the potential upper number of car purchasers is estimated in the car registration model for each country. The constraints to motorisation can be generated with the help of the new income distribution model. As the income distribution model provides information about all income besides capital income, the adult population is assigned to two categories: persons that cannot afford to buy and operate even a used car without falling below national poverty line and persons that can afford to buy and operate at least one car.

Apart from these models which are integrated to measure impacts of income distribution, the car technology model is enhanced by the six most promising alternative car technologies. For this purpose, the previous structure of the car technology model is modified completely. The new approach simulates the decision process of new car purchasers for one out of eight technologies. Rational impacts like all variable, fixed and so-called fuel procurement costs per vehicle-km also irrational decision criteria are considered by the application of a logit function. The final car technology model is able to reflect the development of car technologies in the historical period between 1990 and 2005.

In order to measure the contribution of the new income distribution model and the revision of passenger trip generation, car registration and car technology model to more realistic simulation results, three scenarios are simulated with ASTRA-S and presented in this thesis. The baseline scenario which considers all expected trends as well as consequences of already passed policies until 2007 already demonstrates that an overestimation of motorisation trends can be avoided in the new ASTRA-S model. Economic and passenger transport results indicate moderate growth until the year 2040. Furthermore, the baseline scenario results project that car fleets in EU27 will be still dominated by conventional technologies in 2040.

The simulation results from a scenario, in which all impacts of income distribution are switched off, exemplify the causal effect of the integration of a heterogeneous structure considering different income classes. Negative feedback loops controlling the reinforcing impacts of positive feedback loops can be strengthened by the model modification. The comparison of motorisation, transport and economic trends in the new ASTRA-S model with the previous ASTRA model demonstrate that income distribution impacts transport generation and motorisation significantly.

Finally, simulation results are presented describing a carbon tax scenario for passenger transport which assumes refunding of revenues for the purpose of supporting hydrogen as future clean energy source for transportation. On the one hand, the results explain that the diffusion of an alternative clean car technology like hydrogen can be accelerated significantly without creating further high financial burdens on traffic participants. Results illustrate that such a technological change can boost the economies in EU27 and reduce the dependency on mineral oil. On the other hand, the scenario is chosen to highlight the capabilities of the new ASTRA-S model in the context of sustainability impact assessment of transport and technology strategies.

6.2 Outlook

Based on the new ASTRA-S income distribution model and modifications of other modules, the quality of simulation results are demonstrably improved, ASTRA-S is still a model which reflects a simplified picture of real-world economic, transport and environmental systems. Therefore, at least parts of the ASTRA-S model ASTRA-S can always be improved and disaggregated. Taking into account the level of complexity reached with the ASTRA-S model version, further disaggregation of modules can only be realised by outsourcing of single modules which are not relevant for the purpose of the simulation. In the following still present weaknesses are pointed out and an outlook on further model development is presented.

The first issue which would require further research concerns the income distribution model. Due to the lack of information about the distribution of capital income, this income type could not be considered in the income distribution model at hand. Even if several studies provide qualitative statements about the distribution of capital income, no quantitative distribution is available. Due to the fact that capital income ranges within a minimum share on total income of 14 % in Romania and a maximum of 51 % in Italy (EUROSTAT data for the year 2004), the consideration of capital income would be significant. An income distribution model which could simulate all types of income would provide the required information to improve for example the estimation of consumption per economic sector. Persons in low income classes which are threatened or even fall below poverty line can not afford luxury products and need to spend all their money for essential goods and services, e.g. food, clothing, rental fee and basic medical service. In contrast, persons in high income classes can afford luxury products. Additionally, the saving ratio is significantly different. While poor people need to spend their total income for essentials, rich people are able to put money aside. Ergo, a completion of the income distribution model considering also capital income distribution would be a further value-added in the Macroeconomic (MAC) module.

Another issue which has been observed during the analysis of travel surveys is the impact of income distribution on the average travel distance per year. The British National Travel Survey of the year 2006 identified that the lowest income quintile in Britain travels only 6,600 km per year compared with average 18,700 km per year of persons in the highest income quintile. As these values do not include distances travelled by plane, the actual distance of persons in the highest income quintile will be much higher than the stated. Even the stated difference demonstrates that the destination choice seems to be significantly impacted by the income situation. Even if this fact was observed, the impacts of income distribution could not be integrated in the passenger trip distribution model in ASTRA-S. The main reason for this was the additional computational resources which would be required by an integration of income distribution. As large matrices are computed in the trip distribution model covering at maximum about 37,632 elements (3 trip purposes, 28 origin countries, 4 origin functional zones, 28 destination countries, 4 destination zones) the integration of income distribution would increase those matrices by factor five. The resulting requirement of additional computational memory can actually not be satisfied with state-of-the-art personal computers and the recent Vensim® software package of the year 2008. A solution of this problem would be to outsource large matrix computations via C++ programs or the linkage of the ASTRA-S model with a detailed static transport model like VACLAV (SCHOCH 2004). The linkage which has been tested the first time during the TRIAS project (KRAIL ET AL. 2007) foresees the transfer of ASTRA-S outputs after the completed trip generation stage. The static transport model performs for a multitude of predefined points of time the remaining transport model stages and provides the aggregated output back to the System Dynamics model ASTRA-S.

7 References

Ackoff RL, Emery FE (1972): “On Purposeful Systems”, Aldine Atherton, Chicago.

ADAM (2007): “ADaptation And Mitigation Strategies“. (URL: http://www.adamproject.eu) – Access at July 21st, 2008.

Agassi S (2008): “Launch of Project Better Place in Denmark”. Speech for the Copenhagen Climate Council. (URL: http://shaiagassi.typepad.com) – Access at April 21st, 2008.

Aigner K (1993): “Einkommensverteilung und Einkommensumverteilung“, vol.1404, Europäische Hochschulschriften – vol.5, Volks- und Betriebswirtschaft, Lang, Frankfurt.

Aral (2005): "Aral Studie – Trends beim Autokauf 2005", Aral Press, Bochum.

Ashby W R (1974): “Introduction to Cybernetics“, Methuen, London.

Asimakopulos A (1988): “Theories of Income Distribution”, Recent Economic Thought Series, Kluwer, Academic Publishers, Boston.

Atkinson AB, Bourguignon F (1970): “Handbook of income distribution”, vol.16, pp.261–307, Elsevier North Holland, Amsterdam.

Banse M (2000): “Social Accounting Matrices for 13 European countries for the IASON project“, (URL: http://www.regroningen.nl/irios/iriostables.htm) - Access at July 2nd, 2007.

Bartmann H (1981): “Verteilungstheorie“, Handbücher der Wirtschafts- und Sozialwissenschaften, Vahlen, Munich.

Bates J (2000): “History of Demand Modelling“, published in: Hensher DA, Button KJ (eds) *Handbook of Transport Modelling*, Pergamon, Amsterdam.

Beckmann M (1974): “Personelle Einkommensverteilung in hierarchischen Organisationen“; published in Bombach G, Frey BS, Gahlen B: *Neue Aspekte der Verteilungstheorie*, vol.2, pp.135–151, Mohr, Tübingen.

Bertalanffy Lv (1968): “General System Theory – Foundations, Development, Applications“, George Braziller, New York.

Birkel C (2005): “Einkommensungleichheit und Umverteilung in Westdeutschland, Grossbritannien und Schweden - 1950–2000“. (URL: http://www.lisproject.org/publications/liswps/425.pdf) – Access at July 21st, 2008.

Black A (1990): “The Chicago Area Transportation Study: A Case Study of Rational Planning“, published in: *Journal of Planning Education and Research*, vol. 10, pp. 27-37.

Blümle G (1972): “Vermögensbildung, personelle Einkommensverteilung und Wirtschaftswachstum“, published in: *Kyklos*, vol. 25, No. 3, pp. 457-480.

Blümle G (1975): “Theorie der Einkommensverteilung – Eine Einführung“, vol.173, Heidelberger Taschenbücher, Springer, Berlin.

Bol, G. (2004): “Deskriptive Statistik”, 6th edition, Oldenburg, Munich.

Bork, C. (2000): “Steuern, Transfers und private Haushalte – eine mikroanalytische Simulationsstudie der Aufkommens- und Verteilungswirkungen“, vol.99, *Finanzwissenschaftliche Schriften,* Dissertation, Universität Potsdam, Lang, Frankfurt.

Bossel H (1994): “Modellbildung und Simulation – Konzepte, Verfahren und Modelle zum Verhalten dynamischer Systeme“, 2nd edition, Vieweg, Brunswick.

Brümmerhoff D (1995): “Volkswirtschaftliche Gesamtrechungen“, 5th edition, Oldenbourg Verlag, Munich.

Case K, Fair R (2007): “Principles of Economics“, Oxford University Press, Oxford.

CEC - Commission of the European Communities (2001): “European transport policy for 2010: time to decide“, White Paper, Brussels.

CEC-DGTREN - Commission of the European Communities: Directorate General Energy and Transport (2005): “Energy and Transport in figures: 2005“, Brussels.

Chen TM et al. (2005): “Report on Model Specification and Calibration Results”, deliverable D3 of TRANS-TOOLS project (TOOLS for TRansport forecasting ANd Scenario testing), funded by 6th Framework RTD Programme, TNO Inro, Delft.

Cowan H J (1958): “Time and Its Measurement: From the stone age to the nuclear age“, World Publishing Company, Ohio.

Cowell, F. A. (1995): “Measuring Inequality“, 2nd edition, published in: *LSE Handbooks in Economics Series*, Prentice Hall/Harvester, London.

Creamer D (1956): “Personal Income during Business Cycles”, vol.6, *National Bureau of Economic Research – Studies in Business Cycles*, Princeton University Press, Princeton.

CSO - Central Statistical Office (1992): “Input-Output Balance for the United Kingdom: 1989“, London.

DATS (1955): “Report on the Detroit Metropolitan Area Traffic Study: Part 1 -Data Summary of Interpretation“, Lansing, Michigan.

De Ceuster G (2005): “ASSESS Final Report”, final report of the ASSESS (Assessment of the Contribution of the TEN and other Transport Policy Measures to the Midterm Implementation of the White Paper on the European Transport Policy for 2010) project funded on behalf of the European Commission 6th RTD framework, Leuven.

DFT –Department for Transport UK (2006): “National Travel Survey 2006“, (URL: http://www.dft.gov.uk/pgr/statistics/datatablespublications/personal/mainresults/nts2006/) – Access at December 10th, 2007.

DIW – Deutsches Institut für Wirtschaftsforschung (2003): “Tabellenband Mobilität in Deutschland – Basisstichprobe 2003“, DIW, Berlin.

Domencich TA, McFadden D (1975): “Urban Travel Demand: A Behavioural Analysis“, North-Holland, Amsterdam.

EUROSTAT (1998): “Harmonised Input-Output-Tables for the EU15 Countries“, EXCEL-files provided by EUROSTAT datashop, Luxemburg.

EUROSTAT (2007): New Cronos Database, Theme 3: “Transport”, Online Database, (URL: http://epp.eurostat.ec.europa.eu) – Last Access at April 19th, 2007.

EUROSTAT (2008a): New Cronos Database, Theme 3: "Population and Social Conditions", Online Database, (URL: http://epp.eurostat.ec.europa.eu) – Last Access at May 3rd, 2008.

EUROSTAT (2008b): New Cronos Database, Theme 2: "Economy and Finance", Online Database, (URL: http://epp.eurostat.ec.europa.eu) – Last Access at March 29th, 2008.

Esping-Andersen G (1990): "The three worlds of welfare capitalism", Polity Press, Cambridge.

Forrester JW (1962): "Industrial Dynamics", 2nd edition, MIT Press, John Wiley & Sons, New York.

Forrester JW (1969): "Urban Dynamics", MIT Press, Cambridge MA.

Forrester JW (1971): "World Dynamics", Wright-Allen Press, Cambridge MA.

Forrester JW (1989): "The beginning of system dynamics", Banquet Talk at the International Meeting of the System Dynamics Society, Stuttgart.

Forrester JW (1995): "The beginning of system dynamics", published in: *The McKinsey Quarterly*, no.4, pp.5-16.

Franz P (1997): "Welche Ursachen hat die Spreizung der Lohneinkommen in den USA? – Aktuelle Aspekte der Forschung und der politischen Diskussion", (URL: http://www.iwh-halle.de/e/publik/disc/65.pdf) – Access at May 20th, 2008.

Frenkel M, John KD (1999): "Volkswirtschaftliche Gesamtrechnung", 4th edition, published in: *WiSo-Kurzlehrbücher – Reihe Volkswirtschaft*, Vahlen, Munich.

Friedman M (1953): "Choice, Chance, and the Personal Distribution of Income", published in: *Journal of Political Economy*, vol.61, no.4, pp.277–290 (URL: http://links.jstor.org/sici?sici=0022-3808%28195308%2961%3A4%3C277%3ACCATPD%3E2.0.CO%3B2-1) – Access at May 14th, 2008.

Fuller A T (1976): "The Early Development of Control Theory", published in: *Journal of Dynamic Systems, Measurement, and Control*, vol.98G, no.2, ASME Transactions Journals.

Furness KP (1965): "Time Function Iteration", published in: *Journal for Traffic Engineering and Control*, Printerhall, London.

Galor O, Tsiddon D (1996): "Income Distribution and Growth – The Kuznets Hypothesis Revisited", published in: *Economica*, vol.63, no.250, pp.103–117.

Greenpeace (2007): "Emnid-Umfrage: Bundesbürger wollen Klimaschutz", (URL: http://www.greenpeace.de/themen/klima/nachrichten/artikel/emnid_umfrage_bundesbuerger_wollen_klimaschutz/) – Access at August 26th, 2008.

Grüske KD (1985): "Personale Verteilung und Effizienz der Umverteilung – Analyse und Synthese", vol.26, published in: *Abhandlungen zu den wirtschaftlichen Staatswissenschaften*, Vandenhoeck und Ruprecht, Göttingen.

Gustafsson B, Johansson M (1999): "In Search of Smoking Guns – What Makes Income Inequality Vary over Time in Different Countries?", published in: *American Sociological Review*, vol.64, no.4, pp.585–605.

Gühnemann A (1999): “Methods for Strategic Environmental Assessment of Transport Infrastructure Plans”, Dissertation thesis at IWW, Nomos Verlag, Baden-Baden.

Harrison B, Bluestone B (1990): “The Great U-Turn – Corporate Restructuring and the Polarising of America”, Basic Books, New York.

HBEFA (2004): “Handbook of Emission Factors for Road Traffic”, version 2.1. Environmental Agency Berlin, Infras AG, Bern.

IWW, TRT, ME&P, CEBR(2000): “ASTRA Final Report”, Final report of the ASTRA project funded on behalf of the European Commission 4th RTD framework, Karlsruhe.

Janssen A, Lienin SF, Gassmann F, Wokaun A (2004): “Model aided policy development for the market penetration of natural gas vehicles in Switzerland”, published in: *Journal for Transportation Research Part A*, Elsevier.

JRC, EUCAR, CONCAWE (2007): “Well-to-Wheel Analysis of Future Automotive Fuels and Powertrains in the European Context”, Ispra.

Kanbur R (2000): “Income distribution and development”, published in Atkinson AB, Bourguignon F: *Handbook of income distribution*, Vol.16, pp.791–841, Elsevier North Holland, Amsterdam.

Kármán T (1963): “Aerodynamics”. McGraw-Hill Inc, New York.

Krail M, Schade W (2004): “Quantification of technological scenarios for long-term trends in transport”, final report of LOTSE project, funded on behalf of the Institute for Prospective Technological Studies (IPTS), EU DG JRC, Seville.

Krail M, Schade W, Fiorello D, Fermi F, Martino A, Christidis P, Schade B, Purwanto J, Helfrich N, Scholz A, Kraft M (2007): “Outlook for Global Transport and Energy Demand”, deliverable D3 of TRIAS project (Sustainability Impact Assessment of Strategies Integrating Transport, Technology and Energy Scenarios), funded by European Commission 6th RTD Programme, Karlsruhe.

Krugman P (1996): “The Adam Smith Address: What Difference Does Globalization Make?“, published in: *Business Economics*, vol.31,pp.7-10.

Krupp HJ (1981): “Staatsverschuldung – Mittel oder Hemmschuh der zukünftigen Wachstums- und Beschäftigungspolitik?”, published in Simmert D B, Wagner K D (eds.): *Staatsverschuldung kontrovers*, pp.71-88, Cologne.

Külp B (1981): “Verteilungstheorie“, Fischer, Stuttgart.

Kuhnimhof (2007): “Längsschnittmodellierung der Verkehrsnachfrage zur Abbildung multimodalen Verhaltens“, Dissertation at University Karlsruhe (TH), IfV Schriftenreihe Heft 66/07, Karlsruhe.

Kupper P (2004): “Weltuntergangs-Vision aus dem Computer – Zur Geschichte der Studie Die Grenzen des Wachstums“, published in: *Wird Kassandra heiser?*, pp.98-111, Stuttgart.

Kuznets S (1965): “Economic Growth and Income Inequality”, published in Ders. (ed.): *Economic Growth and Structure*, pp.257-287, New York.

Lammers K (1999): “Räumliche Wirkungen der Globalisierung in Deutschland“, vol.74, *HWWA Diskussionspapier*, (URL: http://opus.zbw-kiel.de/volltexte/2003/1058/pdf/74.pdf) – Access at June 7th, 2008.

Leontief WW (1966): “Input-Output Economics”, Oxford University Press, New York.

Lewis CA (1997): “Fuel and Energy Production Emission Factors”, ETSU report, Deliverable D20 from the MEET project, Didcot.

Luxembourg Income Study (LIS) Micro database (2008): harmonization of original surveys conducted by the Luxembourg Income Study, Asbl. Luxembourg, periodic updating.

Lydall H (1981): “Theorien der Verteilung des Arbeitseinkommens“, published in: Klanberg F, Krupp HJ: *Einkommensverteilung*, vol.92, pp.125–147, Verlagsgruppe Athenäum, Hain, Scriptor, Hanstein, Königstein.

Mayr O (1970): “The Origins of Feedback Control”, published in: *Scientific American*, vol.223, pp.111-118.

Mayr O (1971): “Adam Smith and the Concept of the Feedback System”, published in: *Technology and culture: the international quarterly of the Society for the History of Technology*, vol.12, no.1, pp.1-22.

ME&P (2000): “SCENES European Transport Forecasting Model and Appended Module: Technical Description”, deliverable D4 of SCENES (Modelling and methodology for analysing the interrelationship between external developments and European transport) funded by the European Commission 4th RTD framework, Cambridge.

Meadows DH, Meadows DL, Randers J, Behrens WW (1972): “The Limits to Growth”, Earth Island Limited, London.

Meadows DH (1980): “The Unavoidable A Priori”, published in Randers J (ed): *Elements of the System Dynamics Method*, Productivity Press, Cambridge.

Metcalf CE (1969): “The Size Distribution of Personal Income During the Business Cycle”, published in: *American Economic Review*, vol.59, no.4, pp.657–668 (URL:http://links.jstor.org/sici?sici=0002-282%28196909%2959%3A4%3C657%3ATSDOPI%3E2.0.CO%3B2-V) – Access at March 14th, 2008.

Mincer J (1958): “Investment in Human Capital and Personal Income Distribution”, published in: *Journal of Political Economy*, vol.66, no.4, p.281–302, (URL: http://links.jstor.org/sici?sici=0022-3808%28195808%2966%3A4%3C281%3AIIHCAP%3E2.0.CO%3B2-K) – Access June 19th, 2008.

Mindell DA (2000): “Opening Black´s Box – Rethinking Feedback´s Myth of Origin”, published in: *Technology and Culture*, vol.41, pp.405-434.

NEA, MKmetric, IWW, MDS Transmodal, VTT, Nestear, ISIS, IVT (2005): "ETIS – Statistical Handbook", Report of ETIS-BASE (Core Database Development for the European Transport Policy Information System) funded by the European Commission Competitive and Sustainable Growth Programme, Rijswijk.

Neal D, Rosen S (2000): “Theories of the Distribution of Earnings”, published in Atkinson AB, Bourguignon F: *Handbook of Income Distribution*, vol.16, pp.379–427, Elsevier North Holland, Amsterdam.

Nielsen F, Alderson AS (1997): “The Kuznets Curve and the Great U-Turn: Income Inequality in U.S. Counties, 1970 to 1990”, published in: *American Sociological Review*, vol.62, pp.12-33.

OECD - Organisation for Economic Co-operation and Development (2005): “Pensions at a Glance: Public Policies across OECD Countries”, 2005 edition, Paris.

OECD - Organisation for Economic Co-operation and Development (2003): OECD Online Statistics, (URL:http://cs4-hq.oecd.org/oecd/).

Ortúzar J D, Willumsen L G (1990): “Modelling Transport”, 3rd edition, JohnWiley and Sons, New York.

Pohmer K (1985): “Mikroökonomische Theorie der personellen Einkommens- und Vermögensverteilung – Allokation und Distribution als Ergebnis intertemporaler Wahlhandlungen“, Springer, Heidelberg.

Ramser HJ (1987): “Verteilungstheorie”, Springer, Berlin.

SCENES (2000): Web-Database of the SCENES project (Modelling and methodology for analysing the interrelationship between external developments and European transport) funded by the European Commission 4th RTD framework, (URL:http://www.iww.uni-karlsruhe.de/SCENES/).

Schade W (1997): “Die Grenzen der Umweltbelastung für den Verkehr“, Diploma thesis at IWW, Karlsruhe.

Schade B, Rothengatter W, Schade W (2002): “Strategien, Maßnahmen und ökonomische Bewertung einer dauerhaft umweltgerechten Verkehrsentwicklung“ (Strategies, Instruments and Economic Assessment of Environmentally Sustainable Transport (EST)), Final report on behalf of the German Federal Environmental Agency, Erich-Schmidt-Verlag, Berlin.

Schade W, Mackie PJ, Nellthorp J, Burgess A, Renes G (2004): “Methodological Advances in Project Assessment within a European Context”, deliverable D5 of IASON (Integrated Appraisal of Spatial economic and Network effects of transport investments and policies), funded by 5th Framework RTD Programme, Delft.

Schade W, Krail M, Fiorello D, Martino A (2004): “ASTRA-T: Results of the TIPMAC Policy Scenarios”, deliverable D5 of TIPMAC (Transport infrastructure and policy: a macroeconomic analysis for the EU), funded by 5th Framework RTD Programme, Karlsruhe.

Schade W (2005): “Strategic Sustainability Analysis. Concept and Application for the Assessment of European Transport Policy”, Dissertation thesis at IWW, Nomos Verlag, Baden-Baden.

Schade B, Casamassima G, Fiorello D, Martino A, Schade W, Walz R (2007): “High Oil Prices: Scenarios assumptions and model interfaces”, deliverable D2 of HOP! Project (Macro-economic impact of high oil price in Europe), funded by European Commission 6th RTD programme, Seville.

Schade W, Helfrich N, Wietschel M, Krail M, Scholz A, Kraft M, Fiorello D, Fermi F, Martino A, Schade B, Purwanto J, Wiesenthal T, Christidis P (2008): “Alternative Pathways for Transport, Technology and Energy to Promote Sustainability in the EU”, deliverable D5 of TRIAS project (Sustainability Impact Assessment of Strategies Integrating Transport, Technology and Energy Scenarios), funded by European Commission 6th RTD Programme, Karlsruhe.

Schoch M (2004): “Verwendung feinräumiger geographischer Informationen in aggregierten Verkehrsprognosen“, Dissertation thesis at the Institute for Economic Policy Research (IWW), Universität Karlsruhe (TH), Nomos, Baden-Baden.

SDS (2008): “What is System Dynamics?”, (URL: http://www.systemdynamics.org)– Access at July 9th, 2008.

Shorrocks AF (1980): “The class of additively decomposable inequality measures”, published in: *Econometrica*, vol.48, No.3, pp.613–625, (URL: http://links.jstor.org/sici?sici=0012-9682% 28198004%2948%3A3%3C613%3ATCOADI%3E2.0.CO%3B2-R) – Access at May 17th, 2008.

Smith A (1776): “Inquiry into the Nature and Causes of the Wealth of Nations”, Random House Inc (1937).

Spahn PB, Galler HP, Kaiser H, Kassella T, Merz J (1992): “Mikrosimulation in der Steuerpolitik“, vol.66, *Wirtschaftswissenschaftliche Beiträge*, Physica, Heidelberg.

StaBA – Statistisches Bundesamt (1997): “Volkswirtschaftliche Gesamtrechungen: Reihe 2 Input-Output-Tabellen 1993“, Metzler-Poeschel, Stuttgart.

StaBA – Statistisches Bundesamt (2007): “Volkswirtschaftliche Gesamtrechnungen – Wichtige Zusammenhänge im Überblick“, (URL: http://www.destatis.de/jetspeed/portal/cms/Sites/destatis/Internet/DE/Content/Publikationen/Fachveroeffentlichungen/VolkswirtschaftlicheGesamtrechnungen/Zusammenhaenge,property=file.pdf) - Access at March 10th, 2008.

Sterman JD (2000): “Business Dynamics: Systems Thinking and Modeling for a Complex World”, Irwin McGraw-Hill, Boston.

Stewart F (2000): “Income distribution and development”, University of Oxford, QEH Working Paper, no.37 (URL: http://www3.qeh.ox.ac.uk/pdf/qehwp/qehwps37.pdf) – Access at May 12th, 2008.

Stich A (1998): “Statistische Messung ökonomischer Ungleichheit Stichprobentheoretische Methoden für die Ungleichheitsmessung und ihre Anwendung auf die Analyse regionaler Aspekte der Wohlstandsungleichheit in Deutschland“, vol.90, Quantitative Ökonomie, Eul, Lohmar.

StLA RLP – Statistisches Landesamt Rheinland-Pfalz (2005): “Entstehung, Verteilung und Verwendung des Bruttoinlandsprodukts 1991 bis 2004“, (URL: http://www.statistik.rlp.de/verlag/berichte/P1013_200400_1j_L.pdf) - Access at November 12th, 2007.

Stopher PR, McDonald KG (1983): “Trip Generation By Cross Classification: An Alternative Methodology“, published in: *Transportation Research*, vol.944, pp.84–91, Transportation Research Board, Washington.

Taubmann P (1981): “Die Verteilung von Gesamteinkommen und von Arbeitseinkommen“, published in Klanberg F: *Einkommensverteilung*, vol.92, pp.105–124, Verlagsgruppe Athenäum, Hain, Scriptor, Hanstein, Königstein.

Time (1940): "Narrows Nightmare", (URL: http://www.time.com/time/magazine/article/0,9171,777504-1,00.html) – Access at July 8th, 2008.

Toro F, Hasenauer U, Wietschel M, Schade W (2006): "Technology Trajectories for Transport and its Energy Supply", deliverable D2 of TRIAS project (Sustainability Impact Assessment of Strategies Integrating Transport, Technology and Energy Scenarios), funded by European Commission 6th RTD Programme, Karlsruhe.

Trede M (1997): "Statistische Messung der Einkommensmobilität", vol.42, published in: *Angewandte Statistik und Ökonometrie*, Vandenhoeck & Ruprecht, Göttingen.

Trozzi C, Vaccaro R (1997): "Methodologies for Estimating Air Pollution Emissions from Ships", deliverable D19 of 4th framework research project MEET, Rome.

UN - United Nations (2002): "Statistical Yearbook: 46th edition", CD-ROM, New York.

UN - United Nations (2008): "ISCED 1997 – International Standard Classification of Education", (URL: http://www.uis.unesco.org/TEMPLATE/pdf/isced/ISCED_A.pdf) – Access at March 10th, 2008.

UNIDO – United Nations Industrial Development Organization (2001): "Industrial Statistics Database: 3-digit level of ISIC Code – 1980 – 1999", CD-ROM, Vienna.

Weizsäcker RKv (1987): "Theorie der Verteilung der Arbeitseinkommen", Mohr, Tübingen.

Wiener N (1961): "Cybernetics – or control and communication in the animal and the machine", 2nd edition, (1st edition 1948), MIT Press, John Wiley & Sons, New York.

Worldbank (2001): "World Development Indicators 2001", CD-ROM, Washington D.C.

Zacher D (2003): "Humankapital in der theoretischen und empirischen Analyse bei Gary S. Becker – Darstellung und Kritik", published in: *Rostocker Arbeitspapiere zu Wirtschaftsentwicklung und Human Resource Development*, no.20, Universität Rostock, Lehrstuhl für Wirtschaftspädagogik, Rostock.