Equal Preferences Across Time and Space.
The Case for Global Car Demand and Climate Change

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Scientific evidence indicate ever more clearer that anthropogenic activities releasing greenhouse gas (GHG)[1] emissions are responsible for an increase in the global mean surface temperature that due to the inertia of the climate system can no longer be prevented entirely. Continuing anthropogenic interference with the climate system resulting from an unbroken release of GHG is a threat to humankind and its natural heritage and further aggravates the potential for dangerous climate impacts. Stabilising greenhouse gas concentrations in the atmosphere at a safe level that prevents dangerous interference with the climate system is the objective of climate protection strategies (WBGU, 2003). They consist of reducing future GHG emissions and achieving GHG emissions limits. The Kyoto Protocol, a treaty to the United Nations Framework Convention on Climate Change agreed in Japan in 1997, is a political measure to achieve these targets. It defines, once set into force, binding quantified emission limitation and reduction commitments for industrialised and transition economies specifying that aggregate anthropogenic carbon dioxide equivalent emissions shall be reduced by at least 5 percent below 1990 levels in the first commitment period 2008 to 2012. GHG emissions are yet difficult to quantify due to the variety of sectors and applications these substances stem from, e.g. electricity generation, transport, households, industry and agriculture, and because of the multiple and varying socio-economic drivers that determine the scope of activities relevant to GHG emissions, e.g. population and technology. Quantifying reference/baseline GHG emission trajectories however is a crucial step to draw a picture of future emission budgets from where emission reduction commitments can be derived and corresponding actions and measures to deviate from reference developments be worked out.

Car Consumption as Driving Force of Climate Change

Car consumption has been a key driver of energy use and is thus a relevant factor to consider in climate protection. Emissions of CO_2 from transport in OECD countries have increased more than in any other sector between 1990 and 1999, with road transport accounting for most of the growth (IEA, 2002). Energy use in OECD transport for instance tripled between 1960 and 1990 and the growth of CO_2 emissions was about the same (OECD, 1993). Most of the additional land-based travel is by car and car use is the most energy intensive compared to buses and trains that use less energy per passenger-kilometer at a typical average occupancy level. Today, car consumption absorbs about 21 percent of total oil demand and is by far the largest component of personal transport demand in terms of passenger kilometers travelled, followed by buses, air, two and three wheelers, passenger rail and minibuses. Recent developments indicate that trends will set forth and car energy demand will increase everywhere in the world, most rapidly in developing and newly industrialising countries.

Besides being an important contributor to aggravating the potential of climate change, car consumption constitutes yet one of the pillars of economic welfare of industrialised societies with car production being a major sector of employment and export activities and car demand triggering growth and income generation. Moreover the car has become a necessary commodity shaping modern societies profoundly and with growing intensity, e.g. structures of urban settlements, working and living schemes. The car thus became a symbol of self-determination, high quality of life and today represents a prerequisite of participating in society in major world regions. The diverging stakes make private automobility a catalyst sector to investigate in order to cope with climate change and to explore viable response strategies in the quest for sustainable development, in particular climate change.

Global Consumption Patterns of Car Demand

While car demand in the industrialised world approaches satiation, developing and transition economies are yet at the dawn of comparable car stock growth trajectories, possibly reproducing consumption patterns prevailing in the affluent world. The diffusion of western consumption habits, e.g. by information technology, has contributed to the emergence of a globalised consumption culture displaying a growing convergent behaviour in demand and thus fostering the development of a global consumer class, as reckoned by UNEP (2002). Individuals participating in the global consumer class possess similar lifestyle and preference patterns that originate in industrialised countries' notion of prosperity, wealth and quality of life built on resource and energy intense material goods consumption. Global consumers are directed towards consuming international traded consumer brands and imitating lifestyles. The car is a paramount example of a consumer item that virtually has crossed all borders, thereby reproducing unsustainable consumption trends around the world.

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[1] GHG: Greenhouse gases are Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur hexafluoride (SF_6). The focus here is however on CO2 emissions.

Analysing consumption patterns embrace behavioural and technological facets. Behavioural aspects of car consumption include the quantity of car stock demand and the degree of car use while technological features are concerned with the energy efficiency in terms of gasoline consumption per kilometers driven that results in a certain amount of CO_2 emissions. Figure 1 pictures the historic development of per capita car stock demand in relation to per capita GDP in constant 1995 US $ in eleven world regions from 1960 to 2000. Data behind the graphs consists of time series from 36 countries selected according to data availability, then being averaged and weighted corresponding to the number of population in each country.

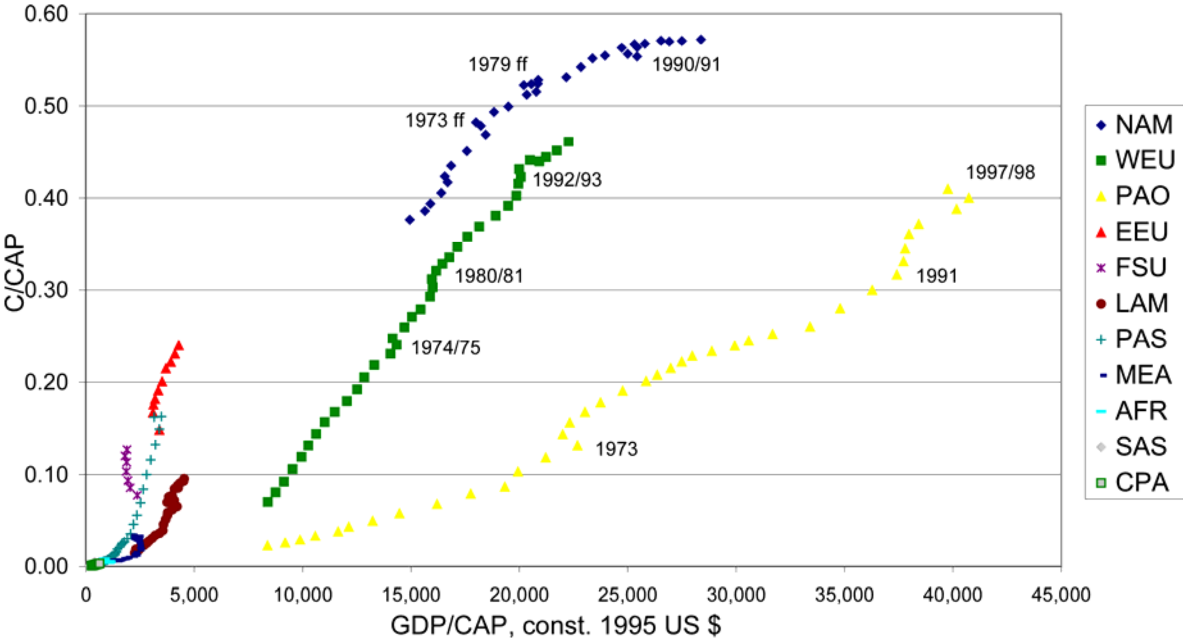

Figure 1: Engel Curve of Car Stock in 11 World Regions

The industrialised regions NAM (North America), WEU (West European Union) and PAO (Pacific Asia OECD) reveal by far the highest car stock per capita ranging from 0.4 to almost 0.6 in 2000 and the highest per capita income levels. Transition and developing regions figure far behind in terms of both per capita car stock demand and income revealing distinct consumption patterns between the affluent and the developing world. Affluent societies being the forerunner of a car centred lifestyle have a leading responsibility in directing consumption towards tolerable energy and resource levels. Automobility figures one of the major societal challenges in that respect.

Determinants of Car Demand

Income appears to be a strong determinant of car demand as it allows for the necessary expenditures to purchase, own and operate a car, yet it does not represent the only

determinant as with the same level of income different levels of car stocks are associated. Further influencing factors of car demand are prices, complementary goods like the extent of the road net system, public transport opportunities as well as geographical and topographical conditions. Last but not least human preferences are drivers of demand. In marginal neoclassical economics they are assigned to be stable and uniform across time and space and given as exogenous variables. Differences in demand behaviour is thereafter explained and modelled in terms of variations in prices and income (Stigler and Becker 1977).
Empirical studies from Zahavi (1981) suggest that people travel on average for about 1.1 hours per day irrespective of culture, geographic origin and level of statistical GDP per capita. [2] The travelling time is however realised by different modes of transport around the world. In developing countries the share of non-motorised mobility, e.g. cycling and walking, is typically high but declines with rising income in favour of motorised mobility while in developed countries the relation is, due to high income levels, the other way around. It follows that total mobility in terms of kilometers driven is higher in developed countries due to higher shares of motorised transport modes, e.g. cars, aviation and high speed trains. Zahavi (1991) further suggests an upper limit of monetary budget to be spent on mobility with respect to income. While in industrialised countries people spend about 10 to 15 percent of their income on mobility, developing countries with a low rate of motorization spent about 5 percent of income on mobility. The two hypothesis of anthropological invariants give a clear picture of the correlation between income and travel behaviour. The higher the income the more money is spent on mobility while demand for mobility shifts from non-motorised mobility to faster modes of transport. Differences in travel demand behaviour is thus explained by differences in economic provision and not through differences in regionally and culturally rooted traditions and preferences. This line of reasoning based on empirical findings of transcultural travel time and travel money budgets supports the assumption of consumer economics according to which preferences are assumed constant and uniform across time and space.

Consumer Economics as Modelling Device of Future Car Demand

The economics of consumption seek to understand and explain consumer market behaviour in terms of consumer reactions to changes in income and prices. It derives demand functions that portray the functional relationship between the demand for commodities and given income and price data. This approach to demand analysis is based on utility functions that represent rational individual preference orderings. Demand equations are derived by maximising the consumer's preference representation function subject to the budget constraint such that demand appears as an expression of preferences within the boundaries set by the disposable income. This method of consumer economics is characterised by sound and consistent theoretical foundations of rational choice (Deaton and Muellbauer 1980).

Applying neoclassical consumer economics to model future car stock demand in the eleven world regions is based on constraint maximisation of preferences belonging to a representative consumer of the world cluster in question. The transition from the micro-economics of consumer behaviour to the analysis of gross market demand is referred to as aggregation problem and controversially discussed in the literature, see for instance Kirman (1992). Yet it simplifies the analysis in using aggregate data of countries and country clusters instead of recurring to data on individuals and thus serves the purpose of grasping global consumption patterns. Distributional differences in allocation structures between rich and poor or other categories of distinction are nevertheless completely negated and results therefore only be interpreted as stylised patterns of aggregated market demand. A further stylised concept applied to model global car demand is that of a generic good. Demand is modelled towards two goods, car stock and generic good, whereas the latter comprises the rest of the commodity world besides cars. Modelling the demand of a stock of commodity, e.g. car stock, instead of actual purchases is a particularity to durable goods consumption as utility is not obtained by purchases that only add to existing stocks but from stock-holding and use (Muelbauer 1981). Traditional utility functions applied to model consumer behaviour are Cobb-Douglas, CES (Constant Elasticity of Substitution), and Stone-Geary. The derived demand model for car stock is based on a Stone Geary utility representation and given by the following functional relationship

$$C_{t,r} = \frac{y_{t,r} - \gamma \cdot p_{g_{t,r}}}{p_{c_{t,r}} (1 + \frac{\beta_{g_r}}{\beta_{c_r}})}$$

with C denoting the demand for car stocks, p_c and p_g being the prices of car stocks and generic good, y representing expenditure, β parameters denoting the budget shares[3] spent on car stocks and generic good, and γ representing a subsistence level of demand

[2] Empirical findings are nevertheless valid for country averages only. Disaggregating country demands into urban and country specific travelling behaviour reveals differences in travel time and travel money behaviour.

[3] Marginal budget shares figure in preference functions and determine the allocation of an additional unit of expenditure to relevant commodities, in the demand equation they appear as budget shares measured in terms of percentage of expenditure.

that has to be satisfied in order to let the rest of the disposable income being allocated on cars and generic goods. The above demand equation is indexed with t and r representing the time horizon ($t = 2000,....,2050$) and region (the eleven world clusters). Given the three parameters β_{c_r}, β_{g_g}, and γ the demand for car stock is determined by prices and income or expenditure respectively (expenditure is income minus savings). β parameter values are assigned from household expenditure data of the year 2000 respecting regional differences in expenditure budgets spent on car stock demand.[4] They are set to the following numerical values: 12 (NAM), 11 (WEU), 10 (PAO), 9 (PAS) and 7 in the remaining clusters. The model is calibrated to historical demand data as shown in figure 1 such that the model output for the years 1960 to 2000 validates historical data. In order to model future demands for car stock driving forces, notably expenditure and price time series have to be designated as input variables. Per capita expenditure time series are calculated on the basis of data derived from an optimal growth model that operates on the same regional aggregation developed by Leimbach and Toth (2003). Income time series increase five-fold in global product until 2050, a scenario of high growth that extrapolates current technological and economic trends. Population scenarios taken to calculate per capita expenditure time series assume a population of 10 billion people in 2050, a scenario of high population growth. With respect to price input data, three scenarios have been developed and equally applied to all geographical regions. It is assumed that prices for generic goods are rising on average 1 and 2 percent per annum respectively. Price dynamics for car stocks follow a 1 and 2 percent increase per annum, and a 1 percent decrease per annum respectively. Combining these price developments, three scenarios are applied to model future car stock demand, notably (-1,+2), (+1,+2), and (+2,+1) following the set (p_c, p_g). Modelling results for seven world regions are shown in figure 2.[5]

Model projections first of all validate historical data on grounds of the said calibration. The bifurcation points of each cluster represent the data points from where projections according to the three price scenarios based on one expenditure scenario are modelled, e.g. from 2000 until 2050. The representative consumers demands for car stock per capita (C/Cap) are depicted against their average incomes, yet modelled on the basis of relevant expenditure time series. The three scenarios manifest as three rather distinct car stock demand trajectories. For the region NAM they are labelled, yet there is a uniform pattern throughout all regions with the scenario (-1,+2) indicating the highest

[4] Assigning different numerical values to budget shares in regional clusters is contradicting the assumption of equal preferences. Yet, if they are assigned equal values, , e.g. if developing regions would be assigned industrialised shares, the model cannot validate empirical data and would overestimate present demand.

[5] The remaining three clusters AFR, CPA, SAS are not pictured for reasons of clarity.

demand trajectories, the scenario (+1,+2) resulting in medium demands and the scenario (+2,+1) representing the lowest demands in per capita car stock.

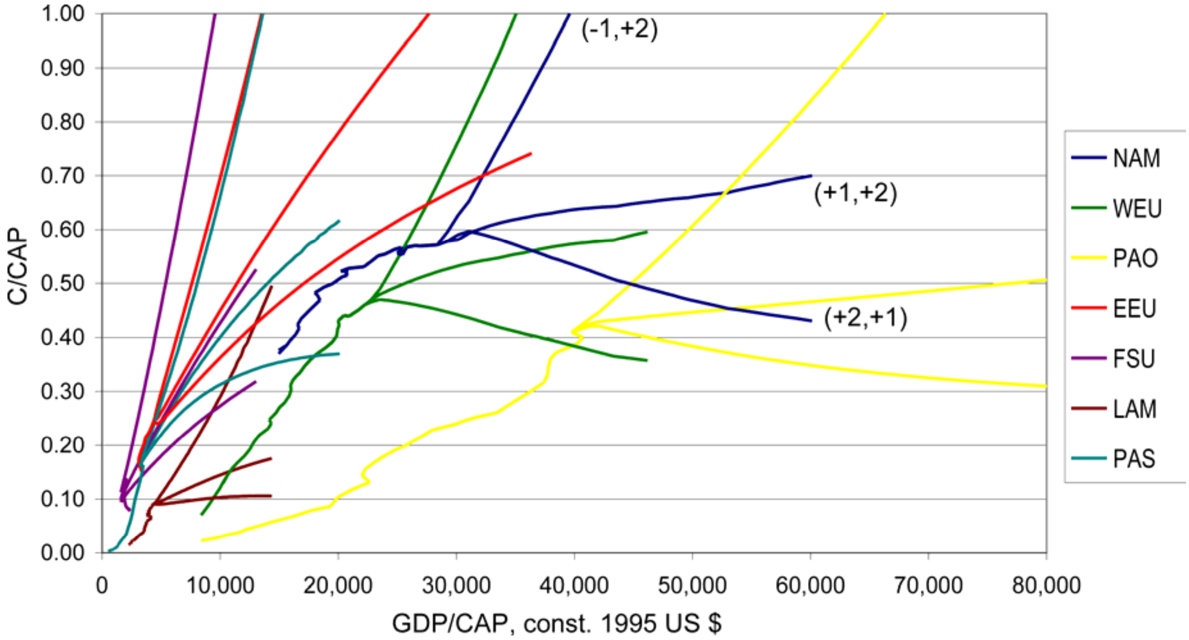

Figure 2: Stone-Geary Car Stock Demand Projections from Three Price Scenarios in Seven World Regions

Modelling results show a considerable gap in output between the three price scenarios throughout all clusters suggesting car stock demands to be fundamentally price sensitive. Car stock demands achieve tremendous levels at the end of the observation period for most of the clusters in the (-1,+2) price scenario, results are not investigated further.

The scenario (+1,+2) yet show results that appear to be reasonable reaching maximum demands in the year 2050 of 0.7 cars per capita in NAM, around 0.6 in WEU and PAO, about 0.5 in PAO and FSU, while the remaining clusters stay rather low in car endowment with LAM achieving 0.18, CPA 0.15, MEA 0.05, SAS and AFR at 0.04. The scenario that assumes a higher price increase in cars than in generic goods (+2,+1) witness a lower per capita car endowment with respect to the other scenarios throughout all clusters. In the end, per capita car stock demands are even below today's figures in the three industrialised regions, indicating a decrease in per capita car stock demands in favour of an increase in generic good demands. Yet, in the remaining clusters car stock demands show growing trends despite of relative price increase and thus higher car stock demands than today. What is striking is the fact that at equal income levels EEU reveals a higher car stock in the (+2,+1) scenario than NAM and WEU in the medium scenarios.

Modelling results are yet strongly directed by empirical calibration. The quality and quantity of available empirical data therefore have a strong impact on the slope of demand function. As for PAS empirical data of the last decades shows superexponential growth, this trend is set forth in model projections. Modelling results are further determined by functional characteristics of the utility function that operates on the basis of constant marginal budget shares and imply demand functions with equally constant expenditure shares. This allows demand to rise with income but yet prevents budget shares to adapt when income rises. The modelling concept thus collides with empirical findings that suggest budget shares of car demand to rise with increasing income reaching a maximum share when markets are saturating. This shortcoming is of particular interest in modelling global long term demand behaviour in developing and transition economies that are today far from satiation and where budget expenditure shares on car consumption are low and expected to rise. Applying this tool to model the demand for cars in these regions, the quantity of consumed goods must therefore be judged to be too low. And indeed, the per capita demand in MEA, CPA, SAS and AFR seems far behind that of the other clusters with higher car stock budget shares. Unless the period of investigation is small enough to prevent budget shares from change or unless investigated regions have already reached maximum shares, the application of consumer demand theory as modelling device needs careful attention and be sensitive towards underestimating demand.

CO_2 Emission According to Demand Projections

Selecting the medium demand scenario (+1,+2) as basis for calculating correlated CO_2 emissions, behavioural and technological aspects of car consumption need to be specified in order to transfer demand projections into emission budgets. Empirical data on driving behaviour in terms of kilometers driven and technological characteristics such as efficiency parameters of the car fleets in use serve as input information from where future behavioural and technological scenarios can be designed and final global emissions projections from car demand be derived. These two components of consumption patterns towards cars are elaborated elsewhere and not being presented here for reasons of limited space (Meyer forthcoming). It shall be noted however, that car fleet fuel consumption is assumed to improve by 1 liter/100 km within 20 years following historical trends.

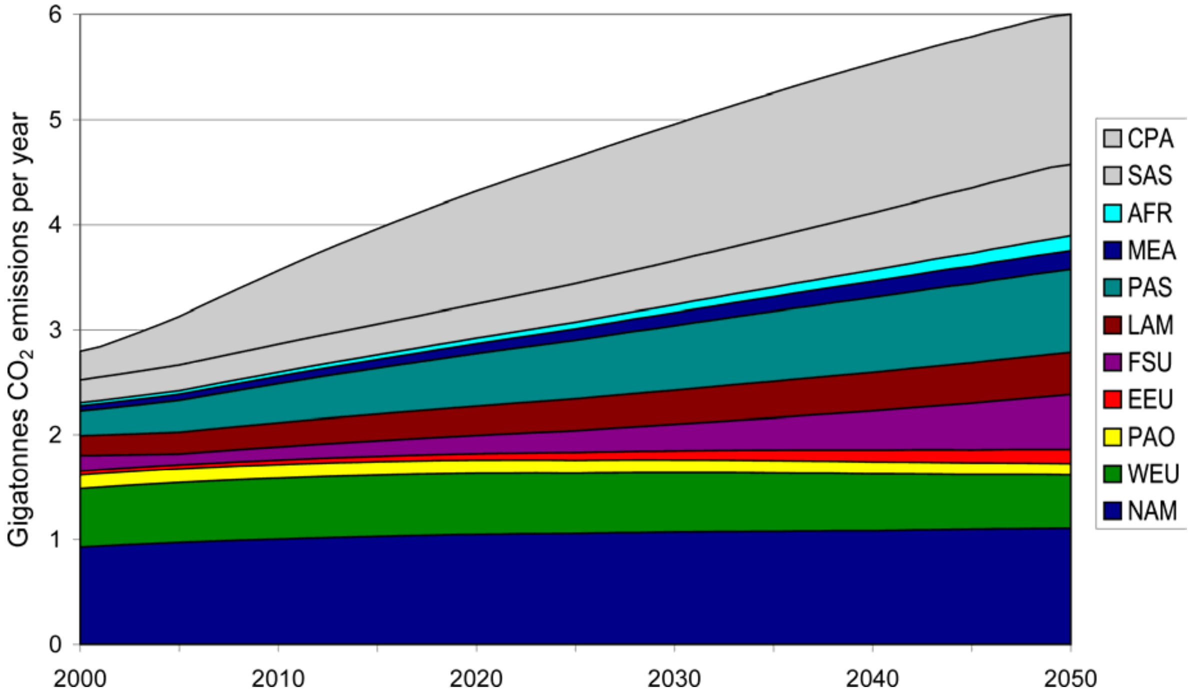

Figure 3: CO_2 Emissions from Car Fleet in use on the Basis of Demand Scenario (+1+2)

Population time series are applied to derive cluster specific car fleets and behavioural and technological scenarios are used to derive emissions budgets. Calculation results are presented in figure 3. Per year CO_2 emissions from global car use approximately double within the observation period of fifty years, rising from 2.8 gigatonnes CO_2 in 2000 to 6 gigatonnes CO_2 in 2050. CO_2 emissions and thus fuel consumption will grow to 27 percent above 2000 levels by 2010 and to 54 (77) percent above 2000 levels by 2020 (2030). Emissions per year rise in all clusters with the exception of WEU and PAO where growth in travel activity is moderate enough not to outweigh fuel economy improvements. All the other regions show increasing CO_2 emissions due to rising on-road transport involvements. Major current emitters are NAM with roughly one third and WEU with one fifth of global private car use emissions, yet CPA and PAS are gaining quickly in CO_2 production, e.g. CPA is reaching one gigatonne CO_2 discharge per year in 2018. These regions hence figure important economies to address when aiming towards demand management and emission control policies.

Conclusions

Theoretical drawbacks of neoclassical consumer economics suggest an underestimation of future car stock demands in regions where car stock budget shares are expected to rise with increasing income, e.g. PAS (Pacific Asia), LAM (Latin America), MEA (Middle East) CPA (China), SAS (India) and AFR (Africa). Per capita car stock demands in these regions indeed stay far below industrialised countries demand (figure 2). Due to high absolute population numbers, per capita car stock demands nevertheless translate into high car fleets and subsequently into high per year emissions (figure 3).

The presented reference development is far from being sustainable and clearly pose a threat to the objective of stabilising climate change. Emissions from car use reach a final scope that today is emitted by all sectors together. Yet modelling results are strongly determined by the modelling assumption of constant and uniform preferences across time and space. Modelling car stock demand on the basis of constant preferences does not allow for changes, in particular for converging budget shares from different initial values between developed and developing regions to a common maximum level, as suggested by empirical evidence. It thus prevents preferences to become uniform when modelled from different starting values as they prevail today. Modelling car stock demand with equal preferences across time and space does further not allow for changes in preferences that may occur as time goes by, e.g. through learning effects that occur due to new insights (e.g. on climate change). Assuming constant and equal preferences can, on the basis of continually growing income, therefore only result in a global reproduction of consumption patterns that presently exist. This method is thus suitable for drawing reference/baseline scenarios, especially in industrialised regions where markets are ripe, or for the analysis of very short time frames, e.g. in sequential modelling. Yet modelling long term scenarios, particularly in developing regions, does involve problems of underestimating demand.

Drawing quantitative scenarios of alternative and sustainable pathways required to demonstrate sustainable patterns of consumption that deviate from reference projections, e.g. declining market shares of car consumption, or declining absolute demand despite of rising income, yet calls for methods that are open to capture the ability to change. This especially refers to changes in preferences beyond the scope of solely adapting to income variations, e.g. changing preferences due to scientific research or experiences gained (learning by doing). Research into preference change is therefore crucial when pursuing on this method. Or alternative and complementary modelling tools of consumer economics have to be taken into account, e.g. econometric approaches that however lack a theoretical backbone.