2. Demand (passenger, main drivers)

Overview

Target

The target of this view is to contribute to the definition of the S-curves that link the following parameters to GDP per capita:

i) the pkm share in air mode (out of total pkm);
ii) the share of pkm on personal vehicles (out of total pkm, excluding air, personal NMT and personal vessels);
iii) the number of people per active bike;
iv) the ownership rate of motorized personal light duty road vehicles (LDVs) for passenger transport;
v) the ownership rate of motorized personal road passenger vehicles (including motorized two wheelers, motorized three wheelers and LDVs); and
vi) the ownership rate of personal passenger vessels for navigation.

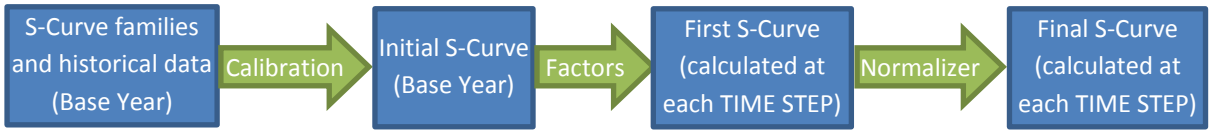
This link builds on information available from historical data, taken from relevant literature and statistics (such as Schafer, 2005 for the evolution of pkm and Dargay et al., 2007 for the evolution of vehicle ownership).

Personal vehicle ownership and pkm shares on personal vehicles are also affected by three factors: the transport characteristic index (intended to reflect the evolution of the transport system on the basis of the shares of pkm on personal/collective passenger transport vehicles), the environmental culture index (aiming to to take into account the effect of behavioural changes associated with environmental consciousness) and the variation of the cost of driving per vehicle km (vkm).

These curves are used in several other views to project transport activity (vkm, pkm) and to evaluate the transport vehicle stock over time.

The definition of all the S-Curves used to generate passenger transport demand is achieved through several steps, schematized in Figure 2.1.

Figure 2.1 Definition of the S-Curves t used in ForFITS to generate passenger transport demand



The first step of the procedure, i.e. the selection of an "initial" S-curve from a family of possible candidates (using the information provided by the user for the base year), is performed in this view. The view also includes the determination of the parameters ("s-parameters") used to modify the initial S-curve (calibrated on base year data) into the "first" S-curve. The latter takes into account of structural the effects of the transport characteristic index, the environmental culture index, and the cost of driving. The last step (normalization), leading to the S-curves that are actually used in the

model for the definition of transport activity ("final" S-curves) will be carried out in each of the "demand" views that focus on a particular segment (e.g. a set of modes) of the passenger demand generation.

Note: ForFITS uses Gompertz functions to define the link amongst various couples of parameters. They are defined by means of four user-defined parameters (SCURVE A, B, C and D) according to the following equation:

$$f(x) = SCURVE\ A \times e^{-SCURVE\ B \times e^{-SCURVE\ C \times x^{-SCURVE\ D}}}$$

S-Curves and Gompertz functions/curves are treated as synonyms in this manual.

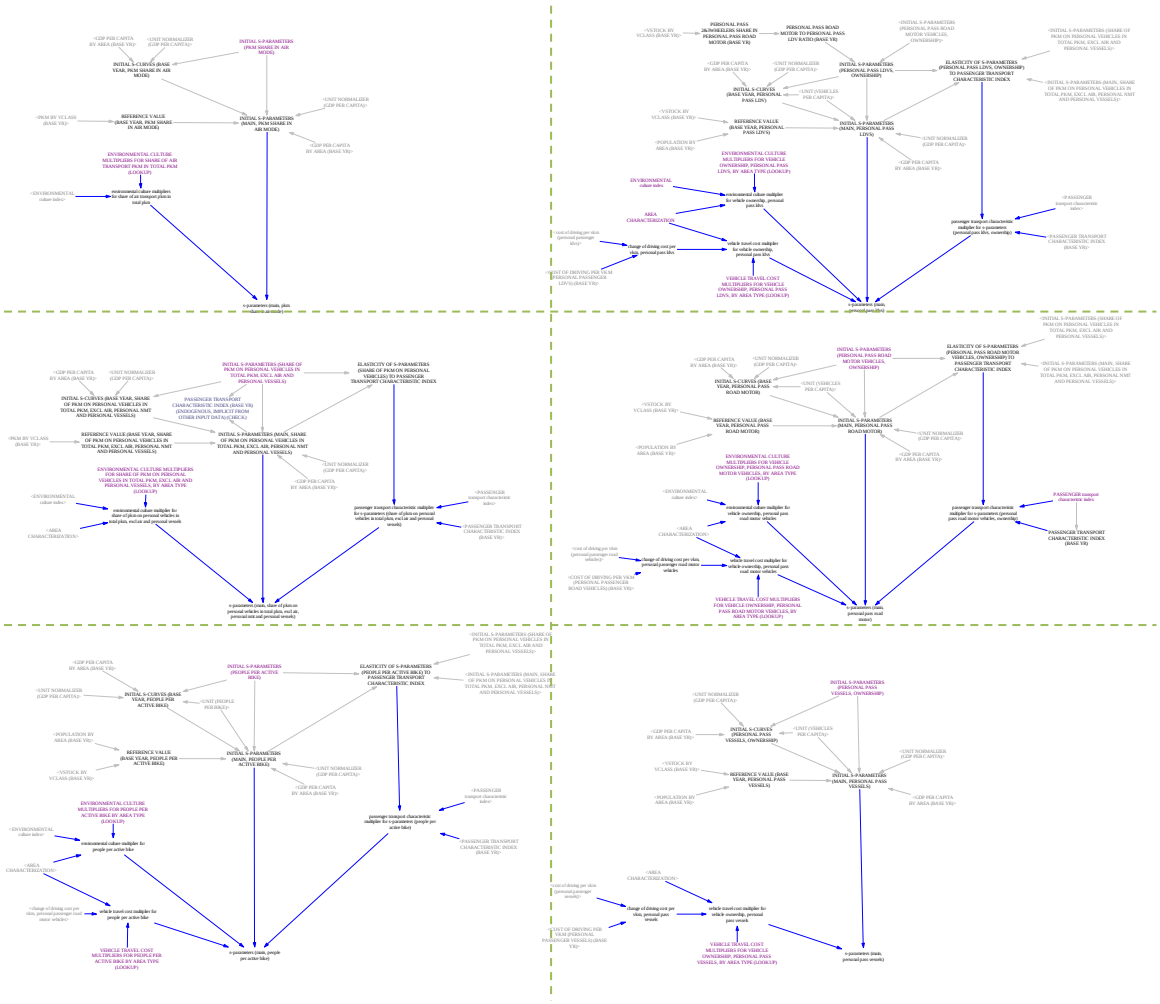
Structure

Figure 2.2 shows the general appearance of the view. The view is structured in six parts, distributed on three rows and two columns to calculate the six variables "S-PAPAMETERS …" that define the "final" S-curves. The calculations are distributed as shown in Table 2.1.

Table 2.1 General appearance of the view

pkm share in air mode	ownership rate, motorized road passenger LDVs
share of pkm on personal vehicles	ownership rate, motorized personal road passenger vehicles
people per active bike	ownership rate, personal passenger vessels for navigation

Figure 2.2 General appearance of the view



Detailed description of the view

Inputs and general calculation flow

In each of the six sets of variables outlined in Table 2.1, the starting point to set the S-Curve is the input "INITIAL S-PARAMETERS…". This defines three guidelines curves (LOW, AVERAGE, HIGH) representing a family of possible development patterns for each of the six variables. A set of input characterizing the S-curve families are included by default in the model. These values, contained in the exogenous input variables "INITIAL S-PARAMETERS (…)" can be modified by the user (although this is not recommended) following the links shown in the input chapter "DEMAND GENERATION PARAMETERS" of the "Table of contents" tab of the ForFITS Excel file (under the headings "Passenger" and "Drivers as functions of GDP per capita").

The GDP per capita at the base year enables to estimate three potential values of each of the six variables according to the three guidelines curves. The GDP per capita is derived from the information on GDP and population provided by the user in the "Socio-economic data" tab of the ForFITS Excel file (refer to the "economic parameters" view for more information on this).

The base year values of the variables included in Table 2.1 are set by the user with the information provided by the ForFITS Excel file through the information contained in the "User inputs (BASE Y)" tab. In Vensim, the base year values of these parameters are stored in the variable "REFERENCE VALUE (BASE YEAR, …)". The comparison between the value of the parameters in the base year and those of the six sets of families of possible guiding curves enable to define six initial S-curves, representing the variables of Table 2.1 as function of GDP per capita, that: i) contain the points representing the base year; and ii) are drawn by means of interpolations between the relevant guidelines curves.

Once calibrated to the base year values, the shape of the six initial S-curves that link each set of variables with the GDP per capita is going to be adjusted over time taking into account the transport characteristic index, the environmental culture index and the cost of driving per vkm.

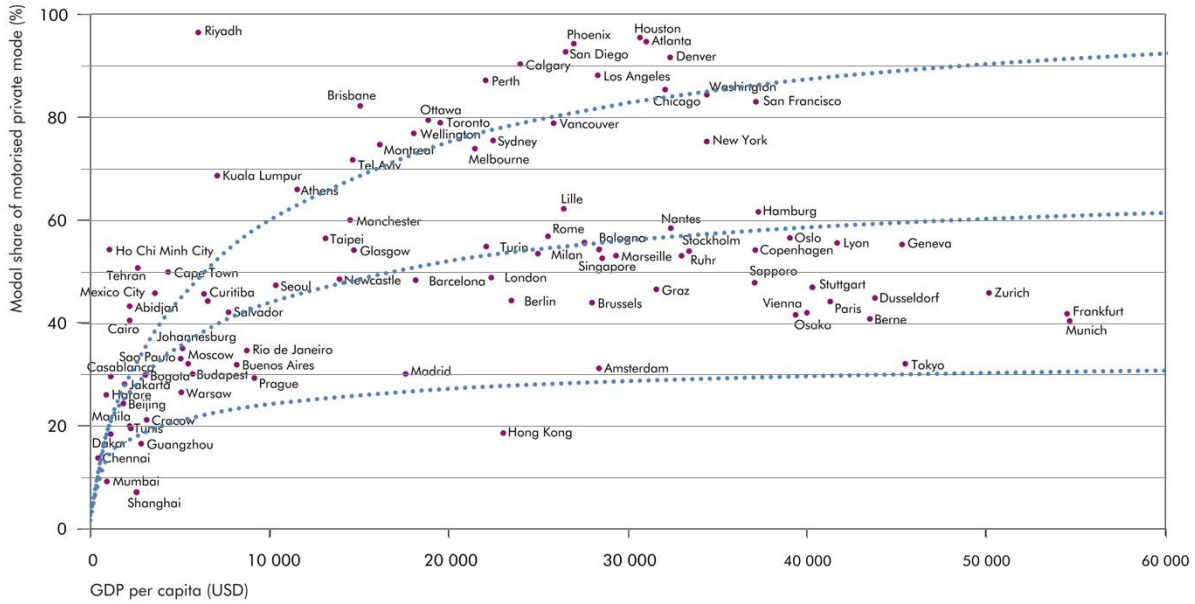
Transport characteristic index

The "transport characteristic index" aims to allow the understanding of the changes associated with shifts to/from private vehicles from/to public transport (i.e. modal shift in passenger transport). It is closely related with the shares of pkm on personal and public passenger transport (excluding air). Its conception exploits the information published in the Mobility in Cities Database (UITP, 2006), and namely the data on the modal share of motorized private vehicles in the total of personal and collective passenger transport vehicles, to identify development patterns of this share as a function of GDP per capita (Figure 2.3) (as suggested in IEA, 2008).

An index of 0 is associated to a share of pkm on personal vehicles that tends to 1 (100%) with the increase of the GDP per capita (above the top blue dotted line of Figure 2.3). In developed countries, this is the case of low population density areas, such as rural area and/or urban agglomerations developed horizontally, with a significant presence of urban sprawl, and where the transport system is primarily focused on personal vehicles. A low transport characteristic index is also very likely to be associated with relatively low taxation of fuels and personal vehicles.

On the other hand, an index of 1 is associated with an evolution of the share of pkm on collective passenger transport vehicles of 100%, while pkm on personal vehicles is reduced to 0% (below the bottom blue dotted line of Figure 2.3). This is an extreme case where the transport system is fully public transport-oriented. A high transport characteristic index (e.g. close to 0.7, as in the case of the bottom blue dotted line of Figure 2.3) tends to correspond urban areas with: i) high population densities; ii) a policy framework that does not incentivise the use (and sometimes the ownership) of personal vehicles (e.g. via parking fees, access restrictions, road pricing, and/or relatively high taxes on personal vehicles and fuels); iii) land use polices and sometimes geographical and/or other constraints that encouraged the vertical development of the city; and iv) appealing, widely available and high-quality public transport.

Figure 2.3 **Pkm share of transport on personal motorised passenger vehicles in total pkm of personal motorised passenger vehicles and public passenger transport (excluding air transport)**



Sources: elaboration of UITP, 2006 (cited by IEA, 2008)

The transport characteristic index represents the asymptotic value of the initial S-Curve that includes the point corresponding to the share of pkm on collective passenger transport vehicles and the GDP per capita at the base year. In other words, the transport characteristic index is equivalent to 1 minus the asymptotic value of the initial S-curve on the share of pkm on personal vehicles (this is stored in Vensim as the parameter SCURVE A of the "INITIAL S-PARAMETERS (MAIN, SHARE OF PKM ON PERSONAL VEHICLES IN TOTAL PKM, EXCL AIR, PERSONAL NMT AND PERSONAL VESSELS)" variable).

At the base year, the transport characteristic index is automatically calculated in the ForFITS Excel file, taking into account for the user inputs on vehicles, travel and loads for the different passenger modes (as entered in the "User inputs (BASE Y)" tab of the ForFITS Excel file). This automatic calculation allows the user to know which index corresponds to the input data that were entered for the regions of interest.

Knowing the transport characteristic index at the base year, the user can determine its evolution by entering, in the ForFITS Excel file ("Transport system (over time)" tab), information on its evolution pattern in period of time under consideration. In the ForFITS Excel file, the exogenous input

"Passenger transport characteristic index" contains the value of the index over time. A link to this variable is located in the input chapter "TRANSPORT SYSTEM CHARACTERISTICS" of the "Table of contents" tab of the ForFITS Excel file.

The elasticities (i.e. the percent change of a driven variable associated with the percent change of a driving variable) that allow taking into account the influence of the transport characteristic index on the shape of the different S-curves are calculated at the base year using the definition of elasticity:

$$E = \frac{\Delta y}{\Delta x} \times \frac{x}{y}$$

In this equation:

- x represents the transport characteristic index at the base year;
- y corresponds to a set of parameters defining the calibrated initial S-curves;
- $\frac{\Delta y}{\Delta x}$ is calculated in each case by means of associating a variation of the transport characteristic index (x) with a change of the y parameters.
  This is achieved by means of linking changes of the transport characteristic index with corresponding changes of the S-Curve families (represented by changes in the y parameters defining them).

Note: the elasticities depend on a component that is defined on the basis of the S-curve families and the transport characteristic index ($\Delta x/\Delta y$) and is not influenced by the particular transport system characterized by the user inputs at the base year, and a component that is specific to each base year transport system (the ratio x/y).

In ForFITS, the transport characteristic index influences two groups of variables: those determining the S-curve on the share of pkm on personal vehicles, and those concerning the S-curves on ownership (bikes, personal passenger road motor vehicles and light duty vehicles (LDVs)).

S-curve on the share of pkm on personal vehicles

The influence of the transport characteristic index on the share of pkm on personal vehicles is calculated considering that a change from 0 to 1 corresponds to a movement across the whole set of curves that define the family of possible patterns for the share of pkm on personal vehicles, from the most personal-vehicle oriented case (HIGH) to the most transit-oriented case (only public transport, 0% share of personal vehicles pkm).

Taking into account that the transport characteristic index represents 1 minus the asymptotic value (parameter SCURVE A) of the S-curves defining the share of pkm on personal vehicles, the elasticity of the parameters defining the share of pkm on personal vehicles to the transport characteristic index is, therefore:

$$E = \frac{SCURVE[HIGH] - SCURVE[(AVERAGE + LOW)/2]}{(1 - PAR.\ A\ SCURVE\ HIGH) - ((1 - PAR.\ A\ SCURVE\ AVERAGE) + (1 - PAR.\ A\ SCURVE\ LOW))/2} \times \frac{INITIAL\ INDEX}{CALIBRATED\ (MAIN)\ INITIAL\ SCURVE}$$

$$= \frac{SCURVE[HIGH] - SCURVE[(AVERAGE + LOW)/2]}{(PAR.\ A\ SCURVE\ AVERAGE + PAR.\ A\ SCURVE\ LOW)/2 - PAR.\ A\ SCURVE\ HIGH} \times \frac{(1 - PAR.\ A\ INITIAL\ MAIN\ SCURVE)}{CALIBRATED\ (MAIN)\ INITIAL\ SCURVE}$$

S-curves on ownership (bikes, personal passenger road motor vehicles and LDVS)

The influence of the transport characteristic index on the variables dealing with vehicle ownership is considered by assuming that a transport system characterized by the lowest guiding curve on share of pkm on personal vehicles would also follow the lowest guidelines curves on motorized personal vehicle ownership (and the lowest curve determining the amount of people per active bike, i.e. the highest amount, at a given level of personal income, of actively used bicycles per capita). On the other hand, the highest guiding curve on share of pkm on personal vehicles is estimated to correspond to an average between the HIGH and AVERAGE guidelines curves on personal vehicle ownership (and people per active bike). The default values used in ForFITS are such that the guiding curves correspond to ownership values that assure coherence with the information embedded in the contextual shares of pkm on private motorized modes.

Taking into account that the transport characteristic index refers always to the share of pkm on personal vehicles (1 minus the asymptotic value), the elasticity of the S-Curves on vehicle ownership as function of the transport characteristic index is calculated as follows:

$$E = \frac{(Ownership[HIGH] + Ownership[AVERAGE])/2 - Ownership[LOW]}{\left(1 - PAR.A_{pkm\ share[HIGH]}\right) - \left(1 - PAR.A_{pkm\ share[LOW]}\right)} \times \frac{INITIAL\ INDEX}{Ownership\ (CALIBRATED\ (MAIN) INITIAL\ SCURVE)} =$$

$$= \frac{(Ownership[HIGH] + Ownership[AVERAGE])/2 - Ownership[LOW]}{PAR.A_{pkm\ share[LOW]} - PAR.A_{pkm\ share[HIGH]}} \times \frac{\left(1 - PAR.A_{pkm\ share\ (INITIAL\ MAIN\ SCURVE)}\right)}{Ownership\ (CALIBRATED\ (MAIN)\ INITIAL\ SCURVE)}$$

The transport characteristic index does not affect AIR or VESSELS.

Environmental culture index

The environmental culture index aims to take into account the effect of behavioural changes associated with environmental consciousness. A value of 1 aims to represent a culture strongly focused on protecting the environment, while a value of 0 considers the case where issues related to the environment are poorly considered. The initial default value is 0.5. In this case, the S-Curves do not receive any modification due to this factor (multiplier of 1). The exogenous input "ENVIRONMENTAL culture index" is the evolution of the index over time according to the data introduced by the user in the ForFITS Excel file ("Transport system (over time)" tab).

The environmental culture index is estimated to have an influence on the S-Curves on vehicle ownership in case of bikes and personal passenger road vehicles, as well as on the S-Curve on pkm share in AIR mode. In particular, an increase of the index provokes a decrease on the personal passenger road vehicles ownership and on the number of people per active bike, but also an increase on the share of pkm in air mode.

The effect of the index on the shape of the curves is achieved by means of multipliers that are applied to the S-Curve parameters A (the asymptotic value of the S-curves) and D (how quickly the asymptotic value is reached). These multipliers are exogenous inputs of the model ("ENVIRONMENTAL CULTURE MULTIPLIERS FOR…"). They have been introduced in the model by default assumptions. The values of the assumptions differ by area type, making a distinction between urban, non-urban and non-specified areas. In urban areas, a move from 0.5 to 1 in the environmental culture index results in a decrease by 5% and 20% for personal road passenger vehicle ownership and for the number of people per active bike, respectively. A move from 0.5 to 0 results in increases of 2% and 20% for the same parameters, respectively. The variations equal 3.5%, 15%, 1% and 10%, respectively, for non-urban areas (reflecting more rigidity because there are fewer alternative options for personal mobility). Averages between the urban and non-urban cases are used for non-specified areas.

The user is required to characterize each area as URBAN, NON-URBAN or NON-SPECIFIED. In this way, the exogenous input "ARE CHARCTERIZATION" enables to apply the appropriate multipliers according to the information provided by the user ("Transport system (over time)" tab in the ForFITS excel file).

Cost of driving per vkm

ForFITS takes into account the influence of the cost of driving on the vehicle ownership of personal motorized road passenger vehicles, personal vessels and on the number of people per active bicycle. In the first two cases, cost variations for a given mode and vehicle class affect the ownership levels in the same mode and vehicle class. In the third case, the changes are based on variations of the cost of driving for personal passenger road motor vehicles. Other cross effects are considered negligible in the modelling approach selected.

Accounting for the effect of the cost of driving per vkm is implemented in the model by means of multipliers that are applied to the S-Curve parameters A (asymptotic value) and D (how quickly the asymptotic value is reached), modifying the shape of the S-curves characterizing the modes concerned by the variation of cost, as explained earlier. A set of multipliers ("VEHICLE TRAVEL COST MULTIPLIERS FOR…"), reflecting the elasticity of vehicle ownership with respect to price, is introduced in the model by default assumptions. The assumptions differ by area type, making a distinction between urban, non-urban and non-specified areas. In urban areas, doubling the cost of driving results in 2% lower personal vehicle ownership, 1% lower ownership of vessels and a 8% lower value of people per active bike (a small effect, if compared with the impact of changes of personal income). The effects are very similar, but with opposite signs, for a halving of the cost of driving. The variations are +/-1.5%, +/-1%, and +/-4%, respectively, for non-urban areas and halving/ doubling costs (reflecting more rigidity to changes because of the lower availability of alternatives). Averages between the urban and non-urban cases are used for non-specified areas.

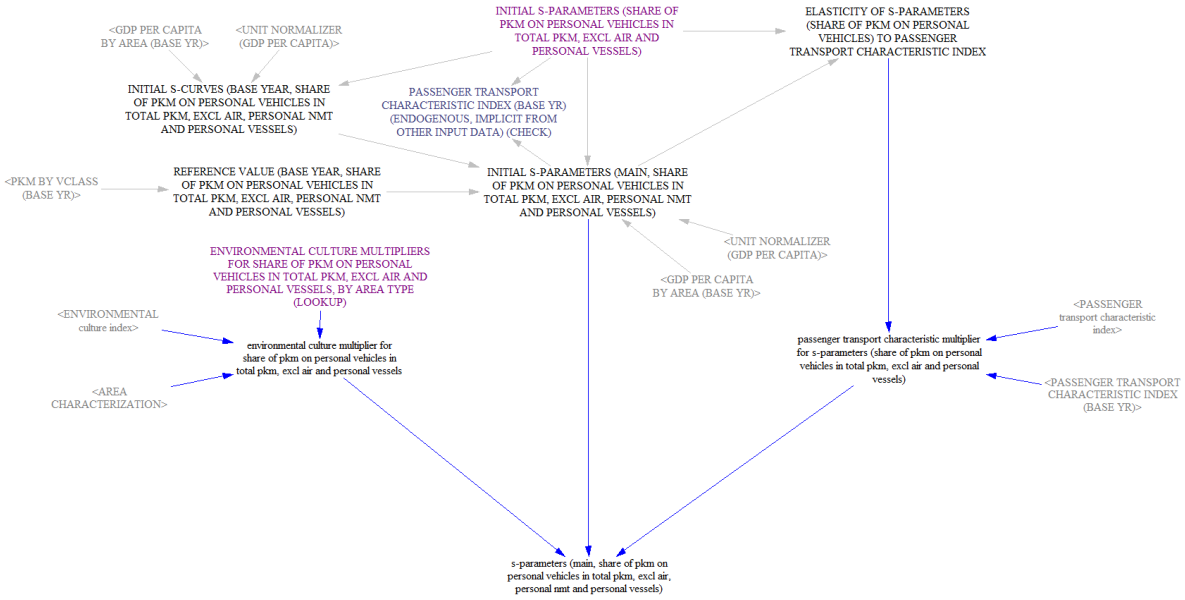
The user selection characterizing an area as URBAN, NON-URBAN or NON-SPECIFIED (mentioned in the section on the environmental culture index) is also valid for this purpose.

Specific calculations and outputs

Share of pkm on personal vehicles (centre left of the view)

Family of S-curves

Figure 2.4 **Zoom on the share of pkm on personal vehicles (out of total pkm, excluding air, personal NMT and vessels)**



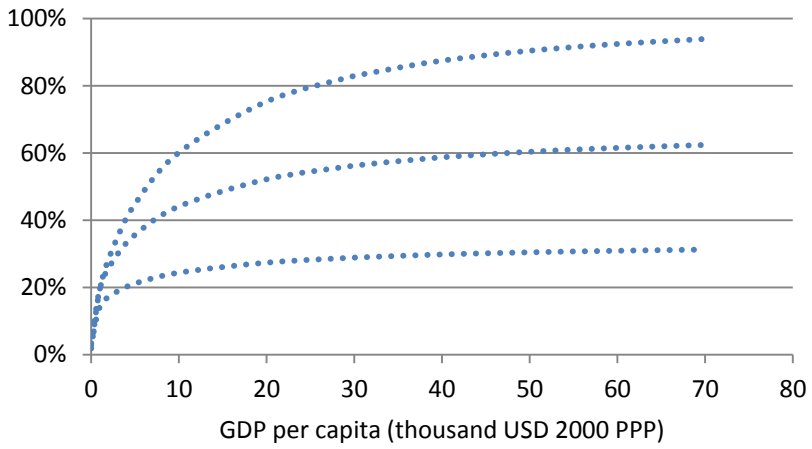
The family of S-curves used to establish the relationship between the GDP per capita and pkm share on personal vehicles (area corresponding to column 1 and row 2 in Figure 2.2 and Table 2.1) is defined by four parameters (SCURVE A, SCURVE B, SCURVE C and SCURVE D) stored in the variable "INITIAL S-PARAMETERS (SHARE OF PKM ON PERSONAL VEHICLES IN TOTAL PKM, EXCL AIR AND PERSONAL VESSELS)".

The equation of each of the representative S-curves is:

$$pkm\ share\ on\ personal\ vehicles = SCURVE\ A \times e^{-SCURVE\ B \times e^{-SCURVE\ C \times \frac{GDP\ PER\ CAPITA}{1000}^{-SCURVE\ D}}}$$

The three sets of parameters (LOW, AVERAGE, HIGH) draw three guidelines curves as in Figure 2.5.

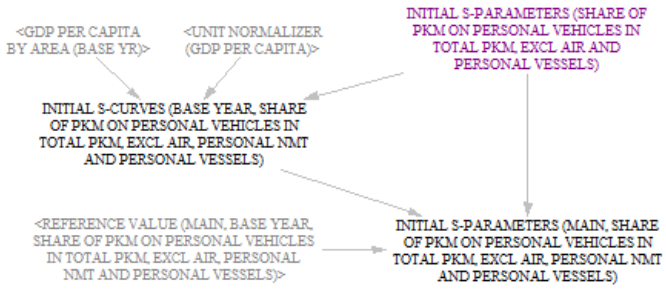
Figure 2.5 S-curve family for the share of pkm on personal vehicles



Initial S-curve

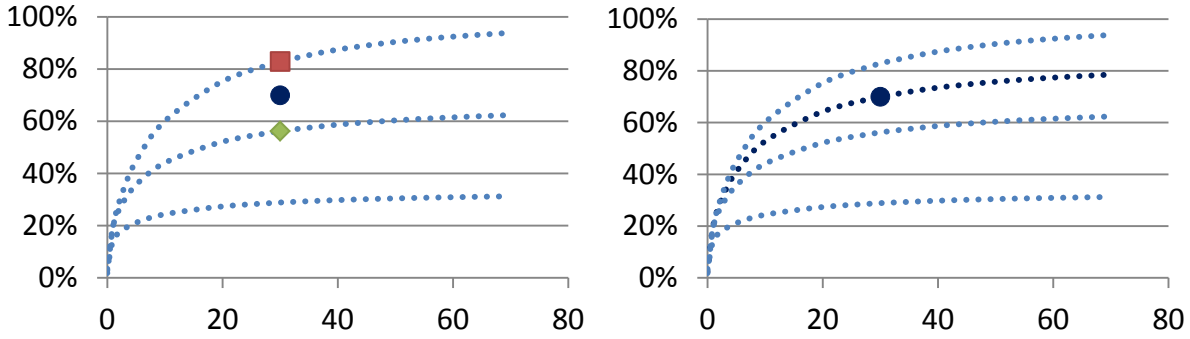
Setting the X-AXIS value according to the input on the GDP per capita at the base year, three potential outputs (Y-AXIS) of the family of possible shares of private passenger vehicles exist. These three values (LOW, AVERAGE, HIGH) are those stored in the variable "INITIAL S-CURVES (BASE YEAR, SHARE OF PKM ON PERSONAL VEHICLES IN TOTAL PKM, EXCL AIR, PERSONAL NMT AND PERSONAL VESSELS)". They are compared with the real Y-AXIS value at the base year, stored in "REFERENCE VALUE (MAIN, BASE YEAR, SHARE OF PKM ON PERSONAL VEHICLES IN TOTAL PKM, EXCL AIR, PERSONAL NMT AND PERSONAL VESSELS" (Figure 2.6), to define the initial S-curve, i.e. the first estimate (before the application of changing factors and the normalization phase for points out of the LOW-HIGH range) of the curve that guides the evolution of the share of pkm on private vehicles, given changes in GDP per capita.

Figure 2.6 Calibration of initial S-curve for the share of pkm on personal vehicles: Vensim sketch



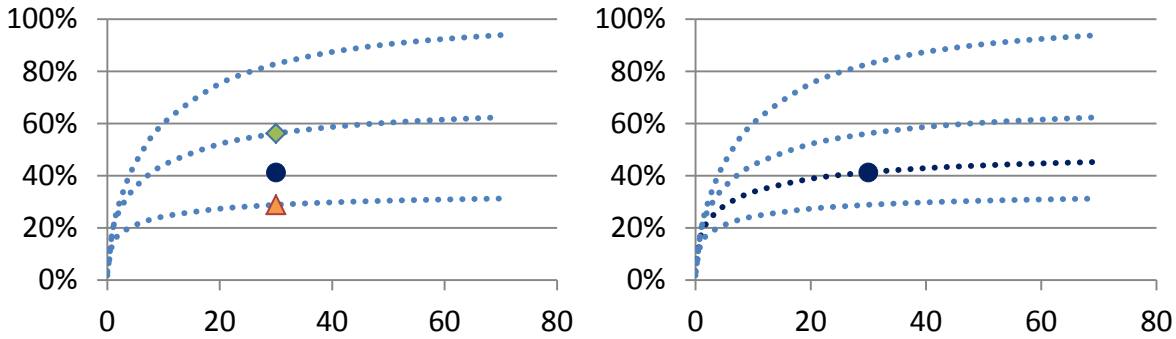
If the real share on pkm on personal vehicles at the base year falls between the values AVERAGE and HIGH S-curves, three S-curve parameters (SCURVE A, SCURVE C, SCURVE D) are adjusted proportionally to the distance between the points and the parameter SCURVE B is calculated ensuring that the reference value fulfils the equation. In this way, the calibrated curve defined by the new four parameters includes the share of pkm on personal vehicles at the base year and follows the trend set by the guidelines curves (),
Figure 2.7),

Figure 2.7 Calibration of initial S-curve for the share of pkm on personal vehicles (case a)



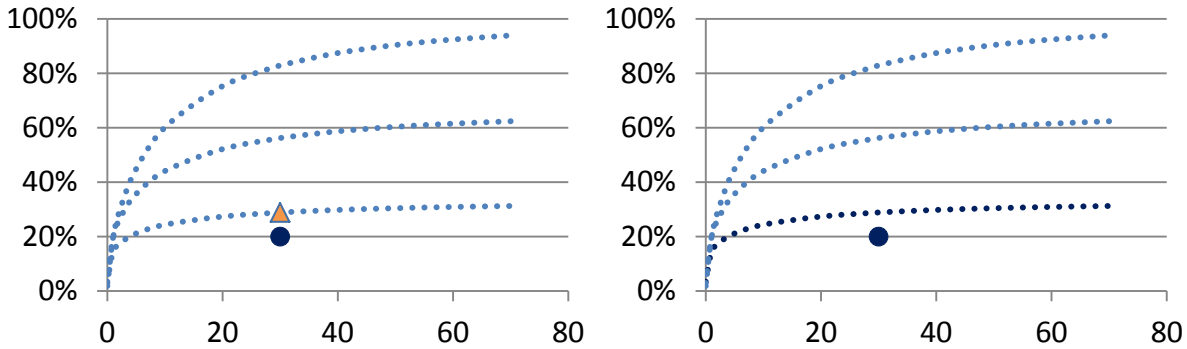
The same logic applies in the case where the real point falls between the values AVERAGE and LOW (Figure 2.8).

Figure 2.8 Calibration of initial S-curve for the share of pkm on personal vehicles (case b)



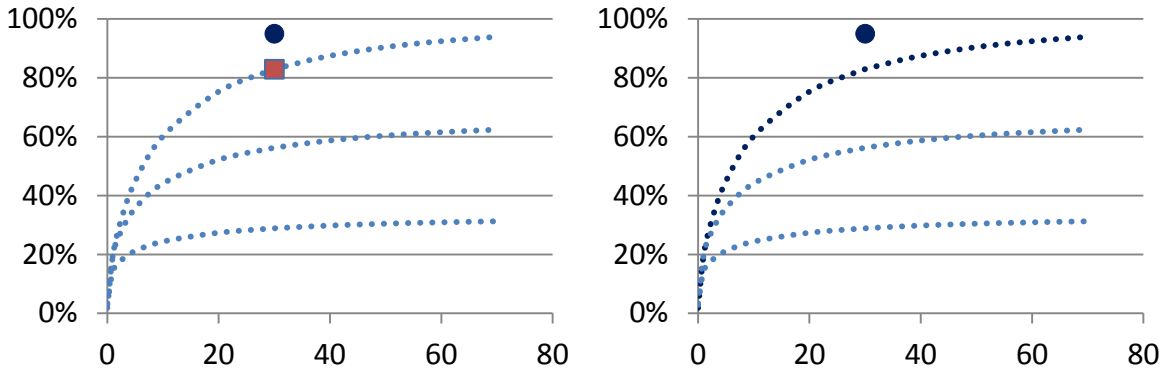
If the share of pkm on personal vehicles in total pkm at the base year falls below the LOW value, then the S-curve parameters are kept as those corresponding to the LOW curve. In this case, the initial S-Curve remains the lowest guiding curve (Figure 2.9). This will be revised further in the normalization phase of S-Curves definition.

Figure 2.9 Calibration of initial S-curve for the share of pkm on personal vehicles (case c)



A similar procedure is followed when the real point is above the limits. In this case, the HIGH curve is the relevant one (Figure 2.10).

Figure 2.10 Calibration of initial S-curve for the share of pkm on personal vehicles (case d)



In Vensim, the variable "INITIAL S-PARAMETERS (MAIN, SHARE OF PKM ON PERSONAL VEHICLES IN TOTAL PKM, EXCL AIR, PERSONAL NMT AND PERSONAL VESSELS)" contains the S-curve parameters that define the calibrated initial S-Curve (i.e. the curve drawn in dark blue in the examples of Figure 2.7 to Figure 2.10).

First S-curve

Over time, the pattern used to define the evolution of the share of pkm on personal vehicles can be adjusted through the elasticity of the share of pkm on personal vehicles to the transport characteristic index (for other S-curves, other factors may also be involved). The new S-Curve (i.e. the "first S-curve") is calculated as the product of the parameters that define the initial S-Curve at the base year and a multiplier that considers the variation of the transport characteristic index compared to its initial value[1].

$$S\text{–}Curve\ parameters\ on\ share\ of\ pkm\ on\ personal\ vehicles\ (over\ time) =$$
$$= Initial\ S\text{–}Curve\ parameters \times Passenger\ transport\ characteristic\ multiplier$$

Where:

$$Passenger\ transport\ characteristic\ multiplier =$$
$$= 1 + Elasticity\ of\ share\ of\ pkm\ to\ trans.characteristic\ index \times \left(\frac{Index\ (over\ time)}{Index\ (Base\ Year)} - 1\right)$$

An increase of the transport characteristic index flattens the initial S-Curve of the share of pkm on private vehicles, while a decrease of the index provokes an upward displacement. For instance, the left parts of Figure 2.11 shows the effect of variation of the transport characteristic index from 0.2 to 0.1 on different calibrated initial S-Curves, while the right-part shows the changes in the same S-curves corresponding to a variation from 0.2 to 0.3.

The variable "s-parameters (MAIN, SHARE OF PKM ON PERSONAL VEHICLES IN TOTAL PKM, EXCL AIR, PERSONAL NMT AND PERSONAL VESSELS)" (Figure 2.12) contains the parameters representing the "first S-Curve" (drawn in green in Figure 2.11). This curve is taken as an input for the normalization phase in the view "demand (passenger, public)". The normalized curve is the used as a reference to forecast the pkm on collective passenger transport vehicles according to the GDP per capita and the cost effects.

[1] At the base year, the calibrated initial S-Curve of the share of pkm on personal vehicles coincides with the first S-curve.

Figure 2.11 S-curve for the share of pkm on personal vehicles: changes due to the transport characteristic index

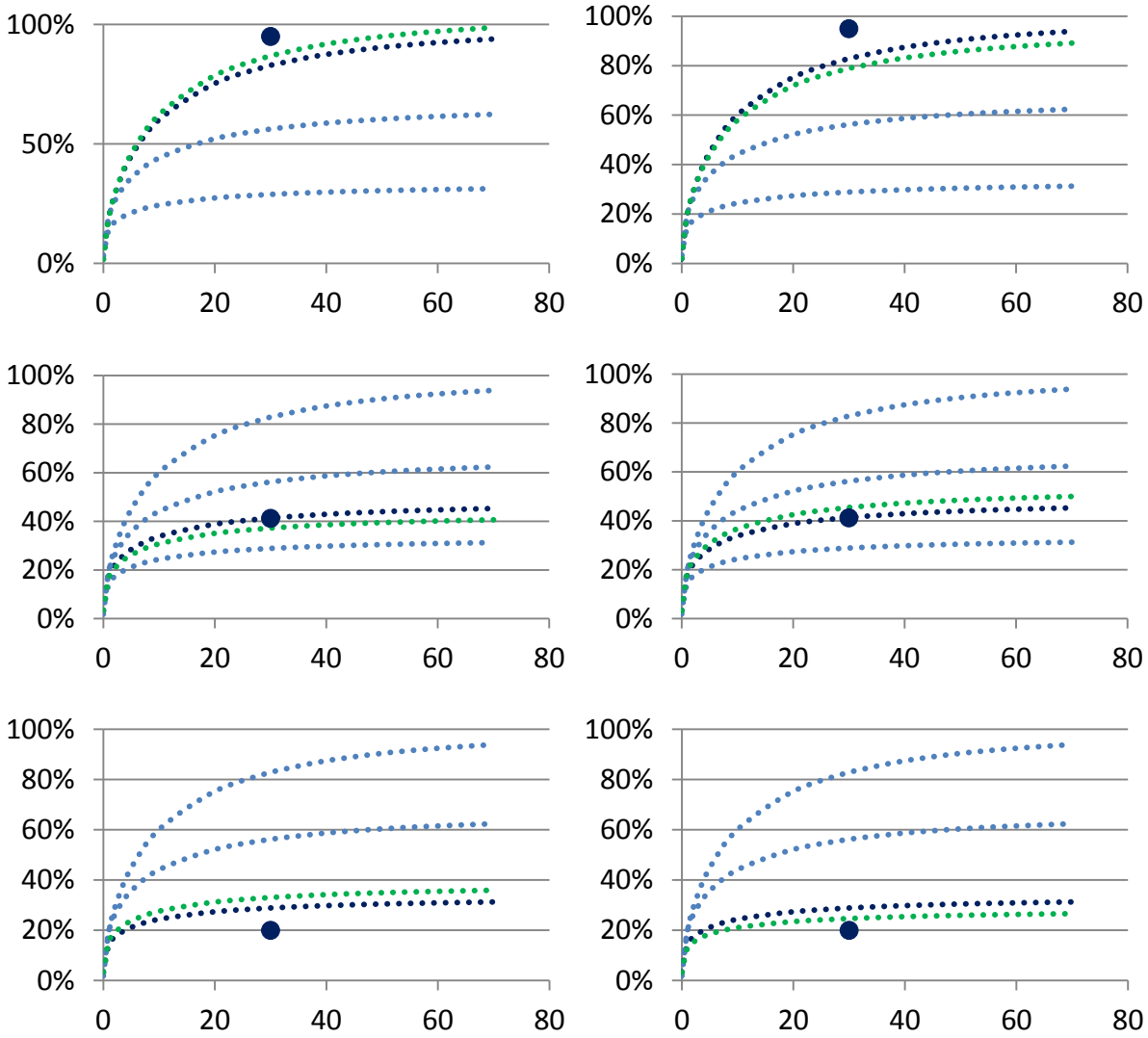
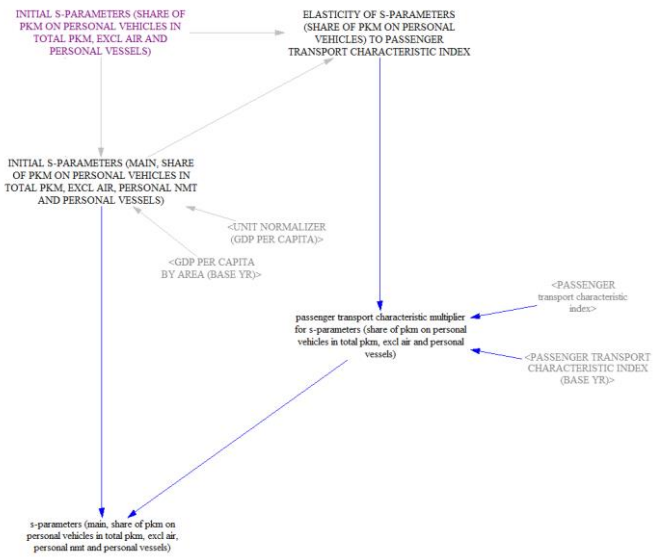


Figure 2.12 S-curve for the share of pkm on personal vehicles: Vensim sketch



Personal passenger road motor vehicles ownership (centre right of the view)

Family of S-curves

Figure 2.13 **Personal passenger road motor vehicles ownership: Vensim sketch**

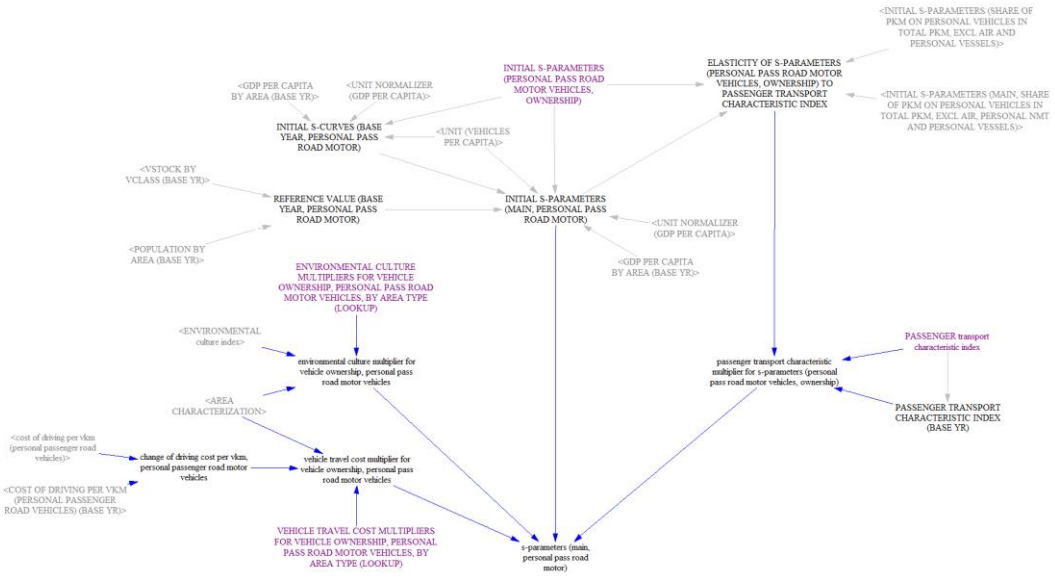
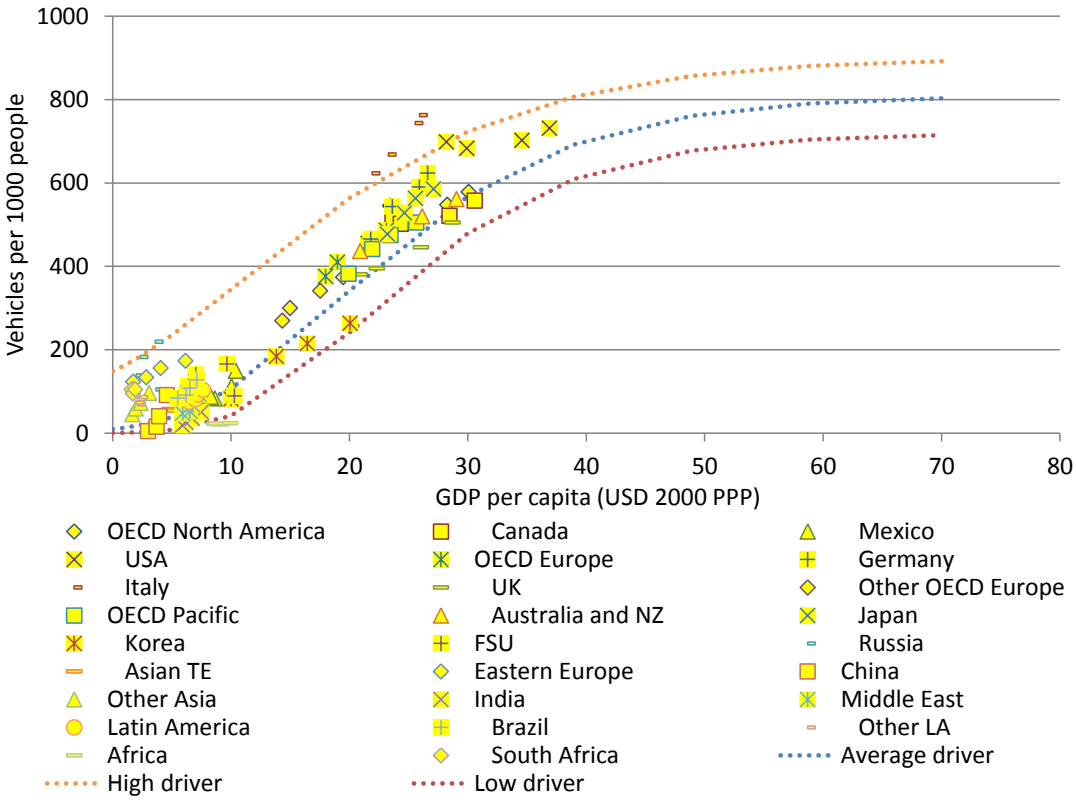


Figure 2.14 **Personal vehicle ownership (two wheelers, three wheelers and LDVs)**



Sources: elaboration of information collected from national statistical offices and international databases, building on those referenced in UNECE, 2012

Passenger road motor vehicles include the vehicle classes from A to D within the modes TWO WHEELERS, THREE WHEELERS and LDVS. The ownership of these vehicles is a variable that can be expressed as function of the GDP per capita by means of S-curves defined by the equation below.

$$Vehicle\ ownership\ \left(\frac{vehicles}{people}\right) = SCURVE\ A \times e^{-SCURVE\ B \times e^{-SCURVE\ C \times \frac{GDP\ PER\ CAPITA}{1000}^{-SCURVE\ D}}}$$

Three sets of parameters define three patterns (LOW, AVERAGE, HIGH) used as guidelines to define the evolution of personal vehicle ownership, given changes in GDP per capita.

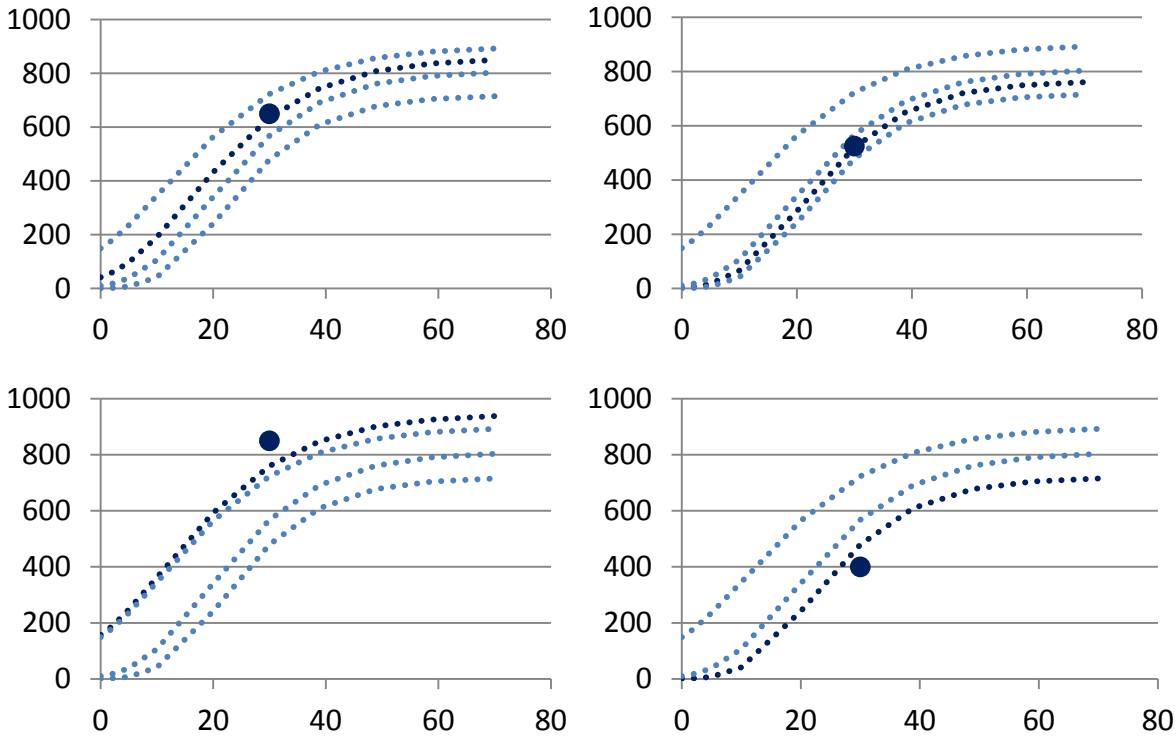
Figure 2.14 shows a plot of points corresponding to historical vehicle ownership data – resulting from a research effort that considered a wide range of statistics from national statistical offices and international databases, such as those referenced in UNECE, 2012 – and the driving patterns defined in ForFITS by default.

Initial S-curve

The outputs given by the three curves when pointing the GDP per capita at the base year are compared with the real initial vehicle ownership easily calculated with the user inputs on vehicle stock and population.

Following the same methodology explained for the S-Curve on share of pkm on personal vehicles, the initial S-Curve on vehicle ownership is calibrated by including the point corresponding to the base year and following the trend of the guidelines curves (Figure 2.15).

Figure 2.15 **Calibration of initial S-curve for the share of pkm on personal vehicles**



If the vehicle ownership at the base year falls beyond the LOW and HIGH limits, the calibrated initial S-Curve will not contain the point corresponding to the base year. In particular, when the value falls below then the initial S-Curve is considered as the LOW guiding curve. On the other hand, when the base year value falls above then the HIGH guiding curve is taken into account. In this last case, the

asymptotic value of the guiding curve is adapted to proportionally to the gap between the HIGH driver at the base year, the historical value at the base year, and a maximum of 1 vehicle per individual.

First S-curve

At the base year, the calibrated initial S-Curve of the share of pkm on personal vehicles coincides with the first S-curve.

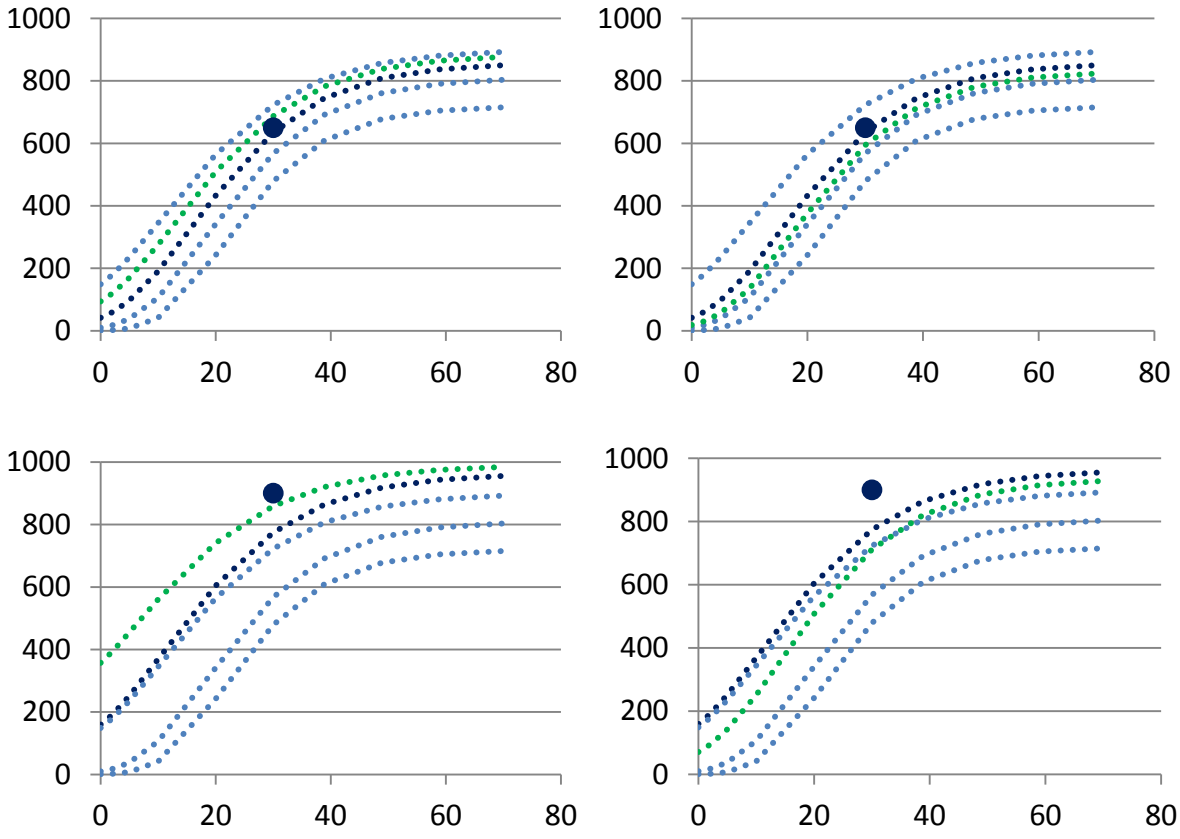
The calibrated initial S-Curve (drawn in dark blue in Figure 2.15) can be modified over time due to variations of the transport characteristic and environmental culture indexes, as well as on the cost of driving per vkm.

According to the definition of elasticity, the multiplier that modifies the initial S-Curve as a consequence of a change on the transport characteristic index is calculated with the following equation.

$$Passenger\ transport\ characteristic\ multiplier =$$
$$= 1 + Elasticity\ of\ veh.ownership\ to\ trans.characteristic\ index \times \left(\frac{Index(over\ time)}{Index(Base\ Year)} - 1\right)$$

The higher is the transport characteristic index, the higher the relevance of public transport is the transport system (and therefore the lower is the relevance of personal passenger road motor vehicles ownership). A decrease of the index triggers an increase of the number of personal vehicles per capita, and vice-versa.

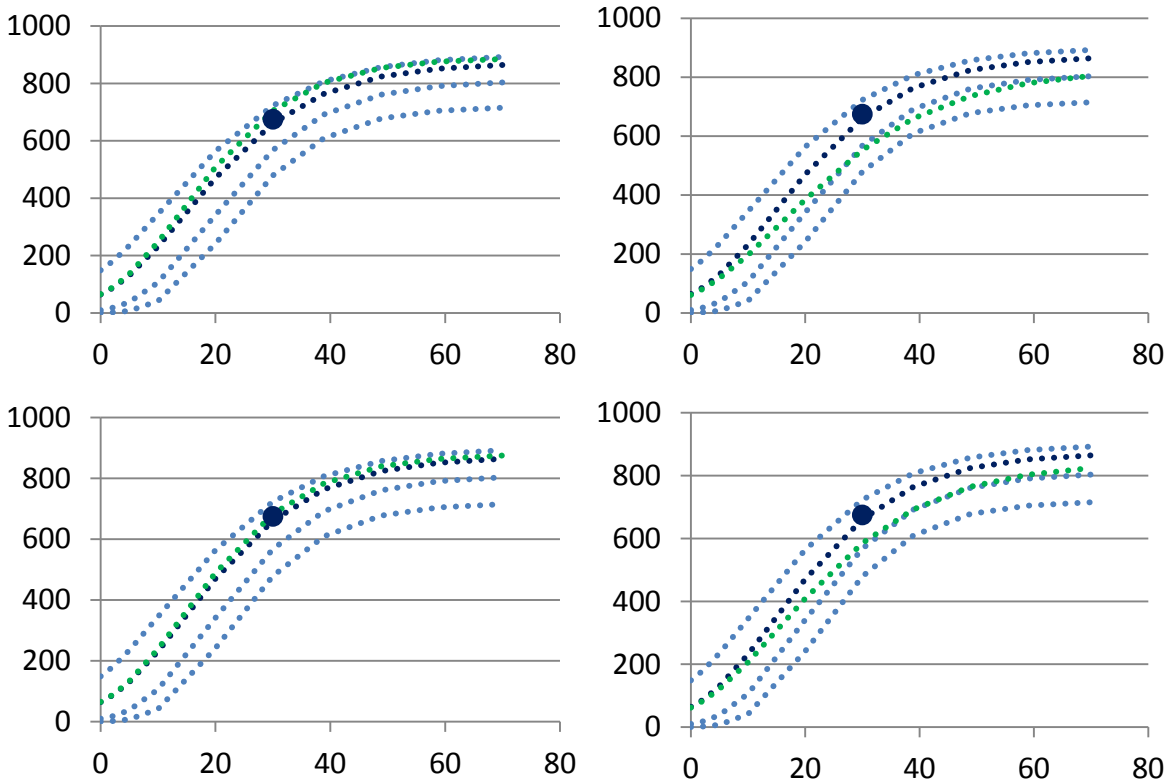
Figure 2.16 **S-curve for personal vehicle ownership: changes due to the transport characteristic index**



The default values used in ForFITS to describe this type of change reflect the logic that transport systems characterized by the LOW guiding curve on share of pkm on personal vehicles are also characterized by the LOW guiding curves on motorized personal vehicle ownership. On the other hand, the highest guiding curve on the share of pkm on personal vehicles is estimated to correspond to an average between the HIGH and AVERAGE guidelines curves on personal vehicle ownership (and people per active bike). This choice takes into account of the characteristics of the location of different global areas shown in Figure 2.3 (where horizontally developed urban areas are characterized by the HIGH driver) and in Figure 2.14 (where developed countries characterized by personal-vehicle oriented transport systems and a tendency to favour horizontal urban developments are characterized by a driving pattern located between the HIGH and AVERAGE guiding curve).

Figure 2.16 shows (in green) the result of changing the transport characteristic index from 0.8 to 1 (left) and from 0.8 to 0.6 (right) for a driving curve below (top) and above (bottom) the HIGH driver.

Figure 2.17 S-curve for personal vehicle ownership: changes due to the environmental culture index



The multiplier reflecting the influence of the environmental culture index on the vehicle ownership is determined by the particular value of the index and on the area characterisation:

$$Environmental\ culture\ multiplier = f(envrionmental\ culture\ index, area\ type)$$

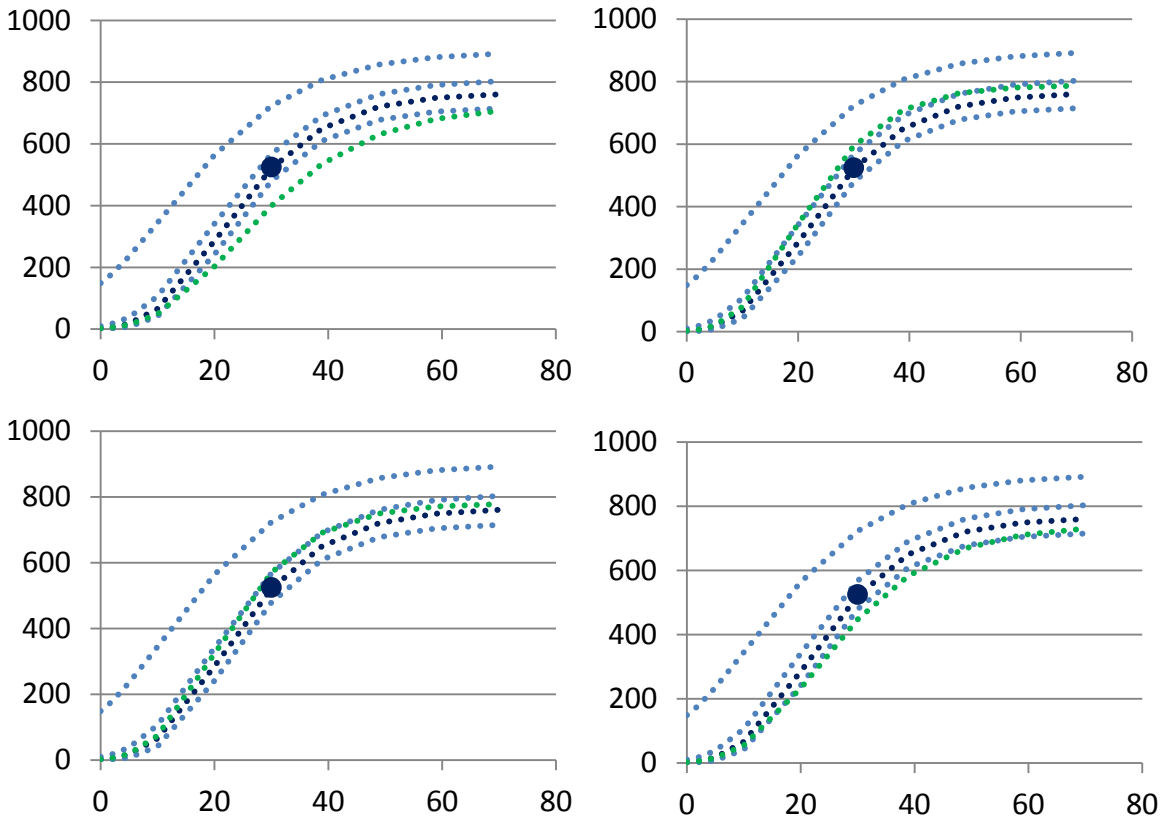
A decrease of the environmental culture index causes an increase on the personal vehicles ownership, while an increase translates into less personal vehicles per capita (the intensity of these effects has been discussed earlier, in the section concerning specifically the environmental culture index). Figure 2.17 shows the modified S-curve (in green) obtained when the environmental culture index varies from 0.5 to 1 (left) and (right) from 0.5 to 0 (the first row corresponds to urban areas and the second row to non-urban areas).

The multiplier that modifies the shape of the vehicle ownership curve as a result of a variation on the cost of driving per vkm depends on the magnitude of the change and on the nature of the area considered (urban or non-urban).

$$Vehicle\ travel\ cost\ multiplier = f(\%\ change\ on\ the\ cost\ of\ driving, area\ type)$$

Reducing the vehicle travel cost increments slightly the vehicle ownership, while raising the cost of driving results in a small reduction of the ownership. Figure 2.18 shows qualitative examples of the impact of increasing the vehicle travel cost (left) and (right) to a reduction of the cost of driving (the first row corresponds to urban areas and the second row to non-urban areas).

Figure 2.18 S-curve for personal vehicle ownership: changes due to the cost of driving per vkm



The environmental culture and vehicle travel cost multipliers affect the parameters A and D of the calibrated initial S-Curve as follows:

$$SCurve\ parameters\ A\ and\ D\ on\ personal\ road\ motor\ vehicles\ ownership\ (over\ time) = \\ = Initial\ SCurve\ parameters\ A\ and\ D \times Passenger\ transport\ characteristic\ multiplier \times \\ \times Environmental\ culture\ multiplier \times Vehicle\ travel\ cost\ multiplier$$

$$SCurve\ parameters\ B\ and\ C\ on\ personal\ road\ motor\ vehicles\ ownership\ (over\ time) = \\ = Initial\ SCurve\ parameters\ A\ and\ D \times Passenger\ transport\ characteristic\ multiplier$$

This leads to the adjusted curve "S-PARAMETERS (MAIN, PERSONAL PASS ROAD MOTOR)" (see Figure 2.13, containing the relevant Vensim sketch).

The variable "S-PARAMETERS (MAIN, PERSONAL PASS ROAD MOTOR)" will be used in the view "demand (pass. personal motor road)" to project the target stock of personal passenger road motor vehicles according to the GDP and population, defining the "first S-curves".

Personal passenger LDVS ownership

Figure 2.19 **Personal passenger LDV ownership: Vensim sketch**

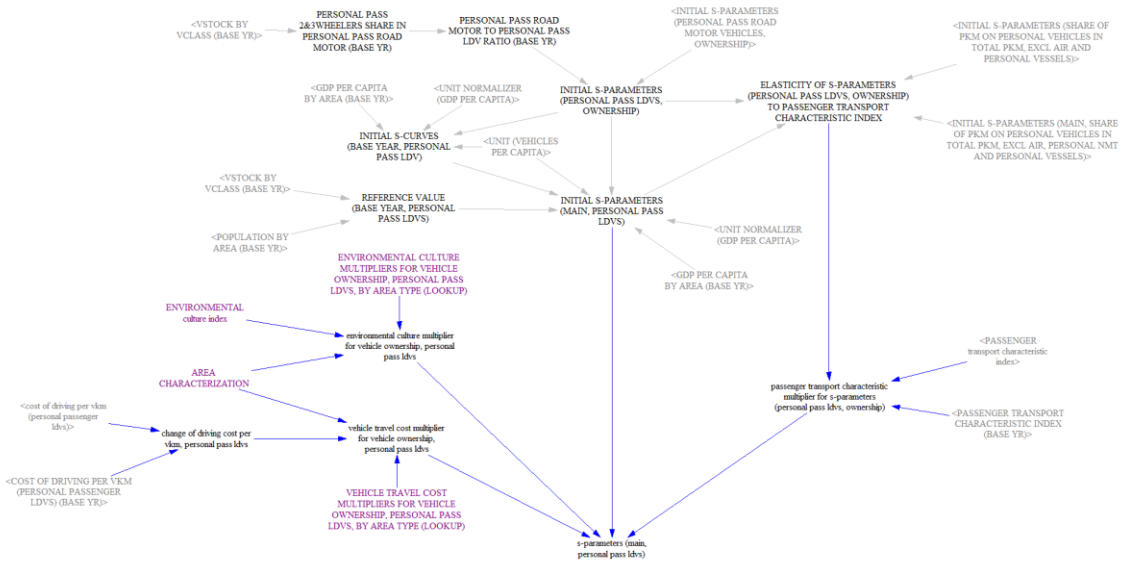
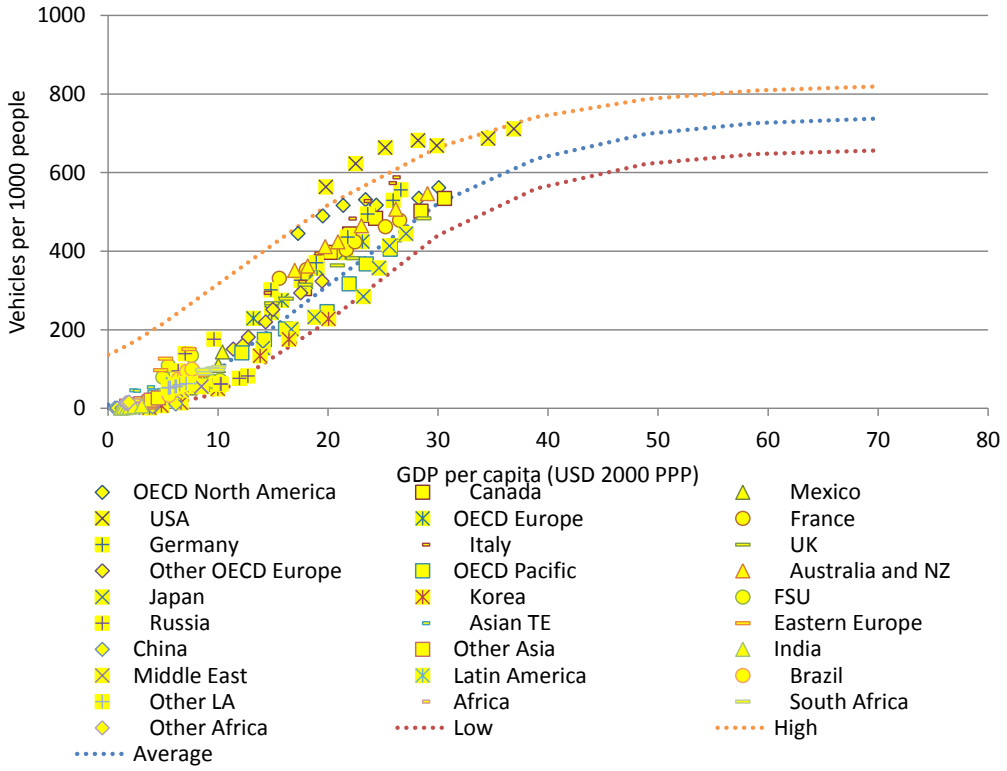


Figure 2.20 **Personal passenger LDV ownership**



Sources: elaboration of information collected from national statistical offices and international databases, building on those referenced in UNECE, 2012

The ownership of light duty vehicles for passenger transport (such as cars) is projected separately as a variable that depends on the GDP per capita, building on a review of statistics focused on information that refer to this specific group of vehicles (Figure 2.20).

The three guidelines curves (LOW, AVERAGE, HIGH) tracing the different patterns are similar to those used in personal passenger road motor vehicles ownership.

The parameters B, C and D of the S-curve are kept, while the parameter A is adjusted:

$$Parameter\ A\ of\ guidelines\ curves\ on\ LDVS\ ownership = \\ = \frac{Parameter\ A\ of\ guidelines\ curves\ on\ personal\ passenger\ road\ motor\ vehicles\ ownership}{Total\ to\ LDV\ ratio}$$

Where:

$$Total\ to\ LDV\ ratio = \\ = Max\left(1 + \frac{TWO\ and\ THREE\ WHEELERS\ in\ the\ stock\ at\ the\ base\ year}{Total\ personal\ vehicles\ (2W, 3W, LDVs)\ in\ the\ stock\ at\ the\ base\ year}, 1.1\right)$$

This approach also allows to project the ownership of two and three wheelers (considered jointly, at this stage), since this can be calculated as a difference between the ownership of personal motorized passenger vehicles and light duty vehicles. The values used by default lead to a growth of passenger two- and three-wheelers per capita that i) is taking place earlier than the growth of passenger light duty vehicles per capita; and ii) is increasingly smoothed (without being reduced) by the growth of passenger light duty vehicles per capita when income increases.

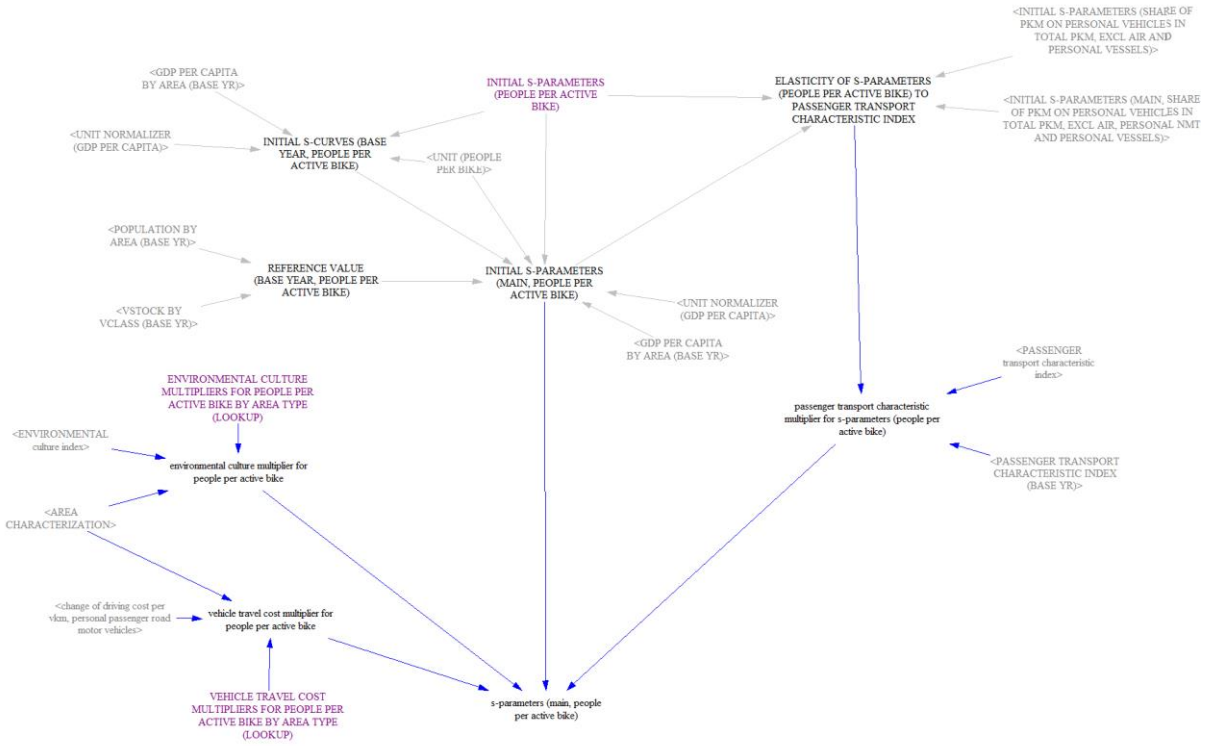
The methodology to calibrate the initial S-Curve as well as the subsequent impact of the indexes and the cost of driving (leading to the fist S-curve) is identical to the procedure explained in personal passenger road motor vehicles ownership. At the base year, the initial S-Curve of the share of pkm on personal vehicles coincides with the first S-curve.

The output "S-PARAMETERS (MAIN, PERSONAL PASS LDVS)" defines the first S-curve. This is used in the view "demand (pass. personal motor road)" as an input to forecast the target stock of LDVs depending on the GDP and the population projections.

People per active bike (bottom left of the view)

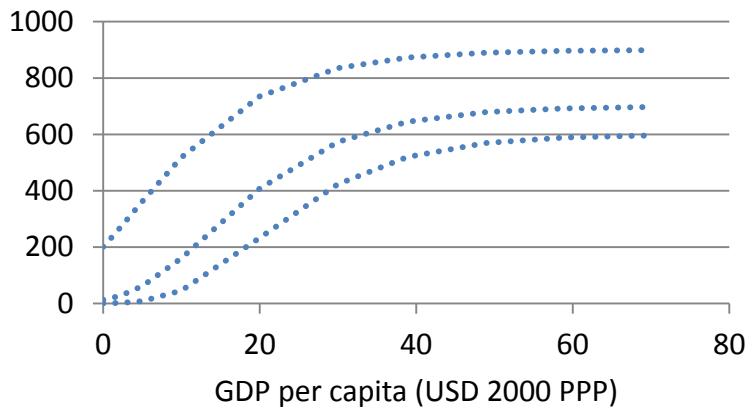
Bicycles are considered in ForFITS as part (vehicle class B) of the NON-MOTORISED TRANSPORT mode. Given that bicycle ownership is not necessarily indicative of the bicycle use, ForFITS takes into account for the amount of "active bicycles" only. The way to do this is the identification of a number of people per active bike. This is linked with the evolution of GDP per capita to reflect the tendency to replace bicycles with motorized transport vehicles once the average income increases (and in correspondence with a growing motorization rate). The limited availability of data on this topic implies that the default values used in ForFITS result from broad assumptions and are to be taken as indicative. Whenever possible, the information concerning the evolution of the number of people per active bicycle should be replaced by analytical instruments resulting from statistical information. In perspective (and depending on the access and/or availability of better information) the approach used in ForFITS may be revised and improved.

Figure 2.21 **Per People per active bike: Vensim sketch**



Currently, the S-curve approach (fully similar to the one described earlier for other parameters) is the mathematical tool used to define estimates of the number of people per active bike. Three S-Curves are traced to identify different patterns (low, high and average evolution), as shown in Figure 2.22.

Figure 2.22 **Number of people per active bike**

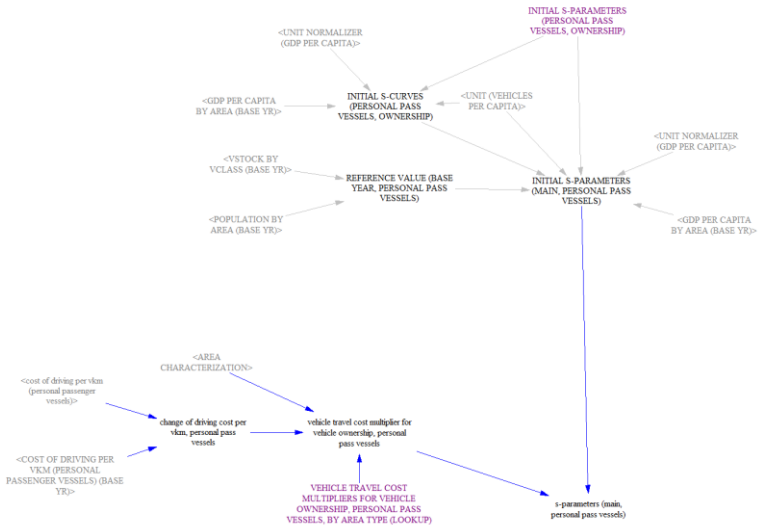


The historical data from the user and the established patterns enable to calibrate the initial S-Curve, which is then modified at each TIME STEP by the multipliers reflecting the influence of the transport characteristic and environmental culture indexes, as well as the cross effect due to the cost of driving of personal road motor vehicles.

The output is the variable "s-parameters (main, people per active bike)" that comes in the view "demand (passenger, nmt)" to forecast the target stock of bikes over time.

Personal passenger vessels ownership (bottom right of the view)

Figure 2.23 **Personal passenger vessels ownership: Vensim sketch**



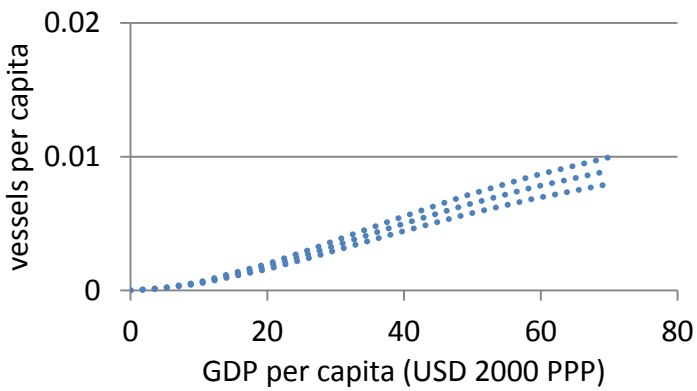
Personal passenger vessels correspond to vehicle classes from A to D in the VESSELS mode. The ownership of these vehicles as function of the GDP per capita depends on the driving patterns (LOW, AVERAGE, HIGH) shown in Figure 2.24. These driving patterns result from assumptions and take into account the following considerations:

i) the ownership of personal passenger vessels is much lower than the ownership of personal passenger vehicles;

ii) the range of GDP per capita corresponding to a stronger growth of the ownership of personal passenger vessels starts and ends at higher levels (the lower limit is roughly three times higher) than the one considered for passenger light duty vehicles.

In addition, the ownership of personal passenger vessels vary significantly, at a given level of GDP per capita, depending on the nature of the area considered (e.g. climate, coastline): the calibration at the base year is therefore key to determine the actual ownership development pattern. In perspective (and depending on the access and/or availability of better information), the definition of the default guiding patterns may be revised and improved.

Figure 2.24 **Driving patterns for personal passenger vessels ownership**



As usual the initial S-Curve is calibrated by means of the trend set by the patterns and the known point in the graph corresponding to the base year. The only factor in this case affecting the initial curve over time is the evolution of the cost of diving per vkm for personal vessels.

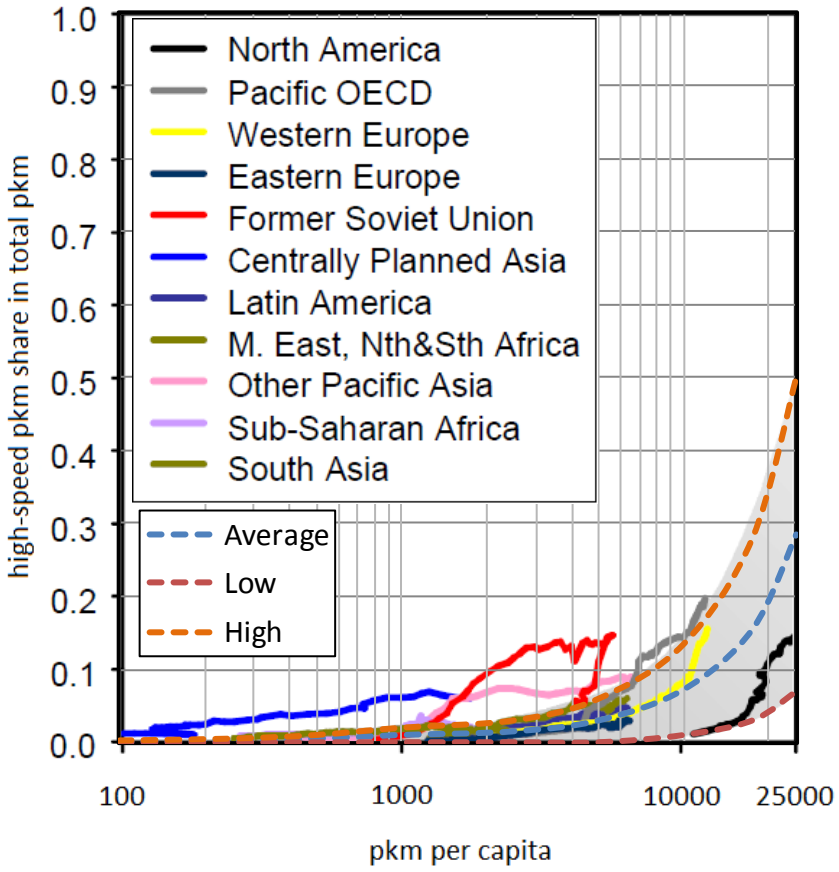
Currently, the transport characteristic index has only been associated with the land transport system. As a result, the impact of the environmental culture index is null for vessels.

The output is the variable "S-PARAMETERS (MAIN, PERSONAL PASS VESSELS)" which is the main input of the view "demand (pass. personal vessels)" to target the number of personal vessels over time.

Share of pkm in air mode (top left of the view)

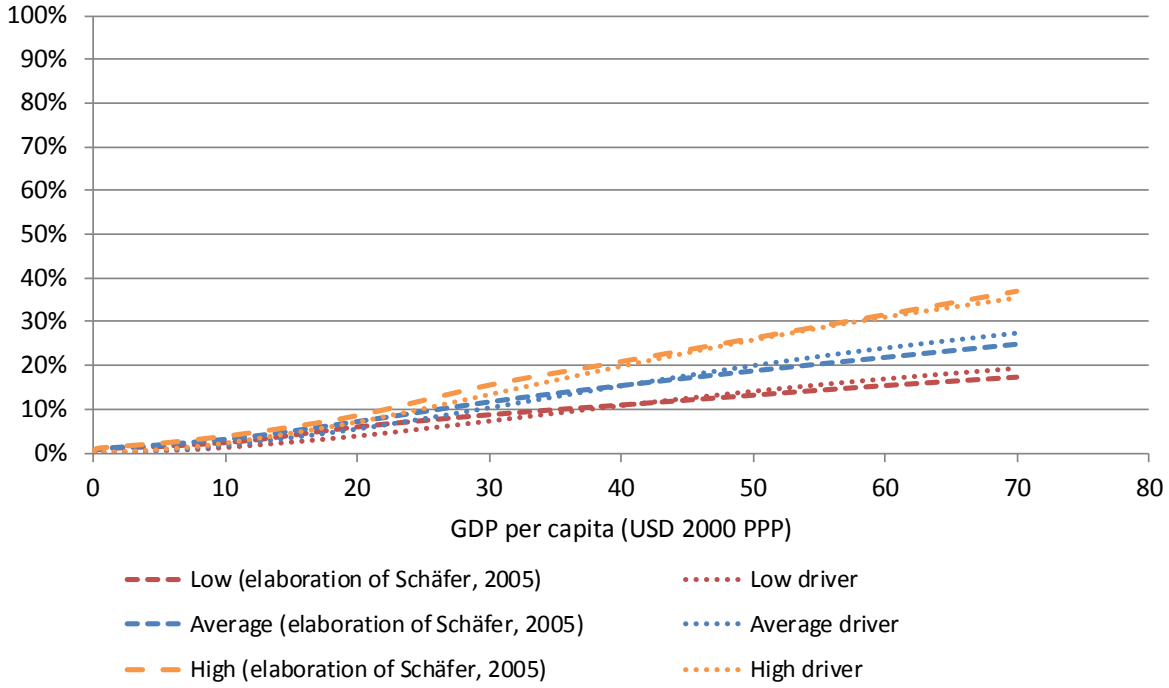
The share of pkm in the air mode in the total pkm including public passenger transport, personal road motor vehicles and personal vessels is also considered as function of the GDP per capita. This interpretation builds on the considerations made by Schäfer (Schäfer, 2005 and Figure 2.25), elaborating the projections on the basis of the observed values of pkm per capita and GDP per capita in Europe. The result of this approach is shown in Figure 2.26, jointly with the default family of S-curves used for the definition of the share of pkm on air (out of the total pkm) in ForFITS.

Figure 2.25 **Pkm share of high-speed transport in total pkm**



Source: elaboration of Schäfer, 2005

Figure 2.26 Pkm share of air transport in total pkm



The initial S-Curve is calibrated according to the usual procedure by means of the S-Curve family and the air transport pkm at the base year. The LOW guiding curve is taken as initial S-Curve when the reference value falls below the range. If the base year value is above the limit, then the calibrated S-Curve results from adjusting the asymptotic value of the HIGH guiding curve proportionally to the reference value and a maximum of 60 % of air transport pkm (CEILING). The only cause that modifies the initial S-Curve over time is currently the evolution of the environmental culture index.

The output is the variable "S-PARAMETERS (MAIN, PKM SHARE IN AIR MODE)", which defines the "first S-curve" (equal to the initial S-curve in the base year) that is used as starting point in the view "demand (passenger, air)" to project the pkm in the air mode according to the GDP per capita and the cost effects.

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