

18. Vehicles, powertrain choice (logit)

Overview

Target

The purpose of this view is select powertrains for new vehicle registrations over time, taking into account of their cost, the costs associated with their use, and user assumptions on the way customers weight the importance of short-term versus long-term costs and savings.

The calculations contained in this view are delayed actively used in the model when the user selects to treat the technology choice "endogenously" (i.e. using instruments that are within the model, rather than using external – or "exogenous" – inputs) in the ForFITS Excel file ("Modelling switches"). This view is not actively used in the model when the user decides to deal with the technology choice "exogenously", i.e. entering information on powertrain technology shares directly in the ForFITS Excel file ("Pwtrn shares" tab).

In the "endogenous" case the Vensim variable "INPUT ON POWERTRAIN SHARES/AVAILABILITY BY VCLASS, NEW REGS (INCLUDING 0/1 INPUT FOR NMT, AIR AND PIPELINES)" contains exogenous inputs on the powertrain technology availability. In the "exogenous" case, it contains directly inputs in powertrain technology shares for new vehicles. In all cases, the powertrain selection of non-motorized modes, air and pipelines are treated in a simplified manner with respect to other modes. These modes are associated, respectively, with a single powertrain technology: "NO POWERTRAIN", "KEROSENE TURBINE" and "PIPELINE PUMP".

Structure

Figure 18.1 Vensim sketch of the view

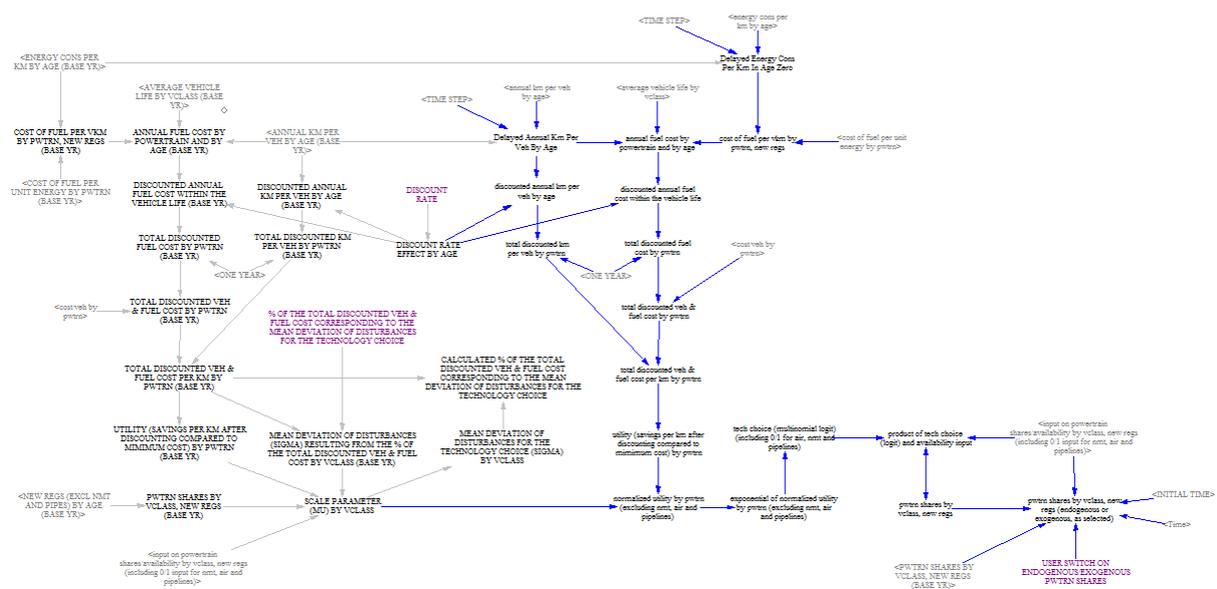
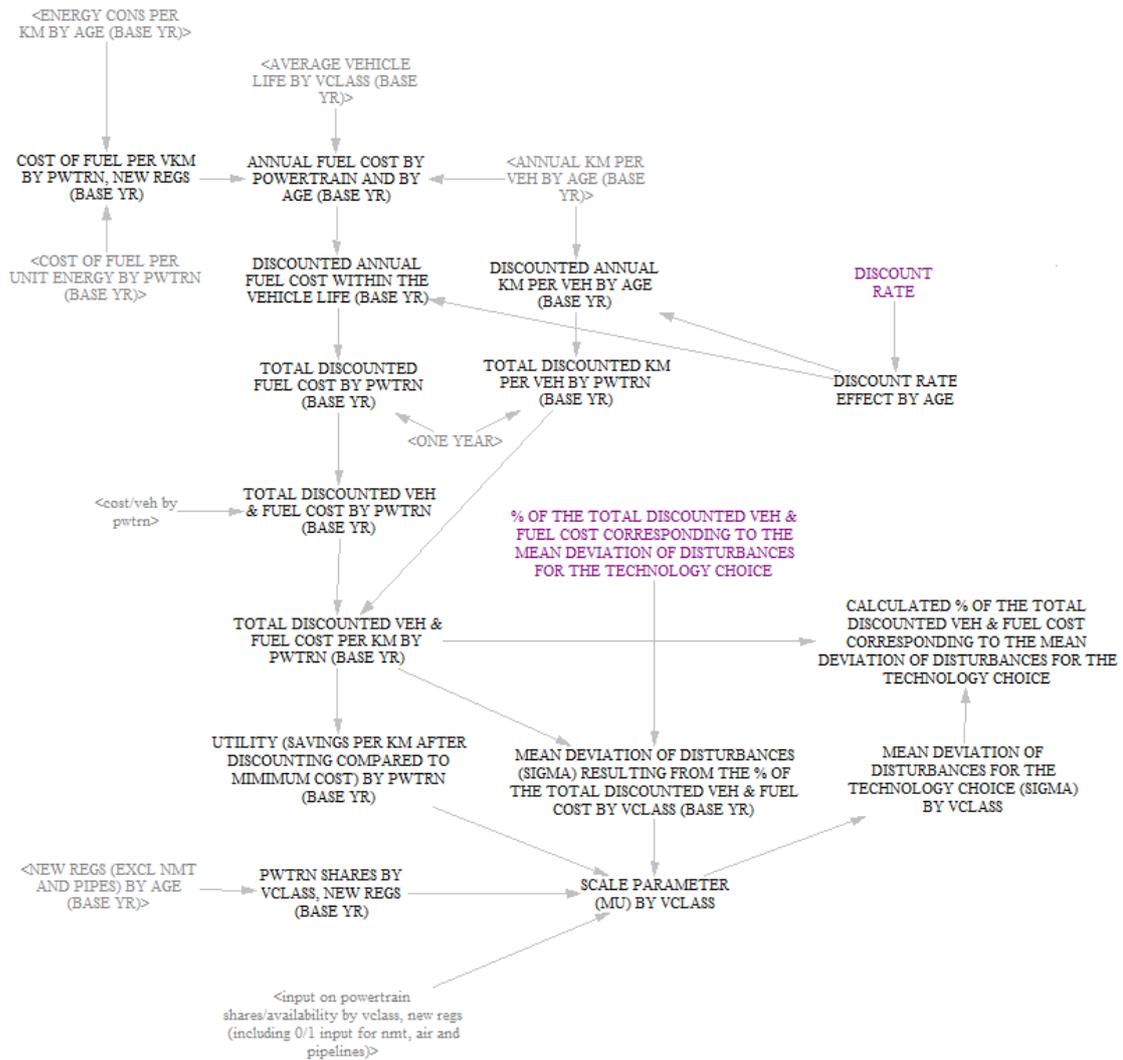


Figure 18.1 shows the structure of this view in Vensim. The calculations concerning the base year, used to calibrate the powertrain selection (especially in those cases when a vehicle class is using different powertrain technology options) are reported on the left, from top to bottom.

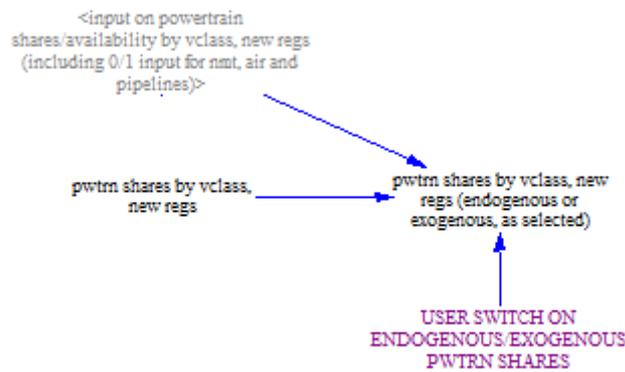
Figure 18.2 Vensim sketch: zoom on the calculations concerning the base year



The right section of the view contains calculations on time-dependent variables, using the calibration information calculated for the base year.

The variable entering information upon the activation or deactivation of the calculations performed in this view is located on the bottom right of the sketch (Figure 18.1 and Figure 18.3).

Figure 18.3 Vensim sketch: zoom on the variables activating the endogenous or exogenous powertrain selection



Detailed description of the view

Inputs and general calculation flow

Once the "endogenous" technology selection is active, the calculations contained in this view combine a multinomial logit approach with exogenous inputs on technology availability to determine the shares of different technology options on the market.

The multinomial logit approach is used to evaluate the probability that a particular powertrain i is selected in the total set of choice (all technologies), given the cost characteristics of all the options available. This is expressed as follows:

$$Probability_{powertrain\ i} = \frac{e^{\mu V_i}}{\sum_{powertrains} e^{\mu V_j}}$$

where $0 \leq Probability_{powertrain\ i} \leq 1$ and $\sum_{powertrains} Probability_{powertrain\ i} = 1$.

This formula assumes that the utility of the choice i , U_i results from a deterministic component, V_i , and an unknown disturbance, ε_i (representing factors influencing the powertrain choice that are not included in the deterministic component):

$$U_i = V_i + \varepsilon_i$$

This formulation also assumes that all the disturbances ε_i are independently and identically Gumbel-distributed¹, with a location parameter η (which is assumed to be zero in this case, indicating that in the absence of disturbances the utility corresponds to its deterministic component) and a scale parameter μ . The latter gives an indication of the importance of the disturbances with respect to the deterministic component of the utility.

¹ The assumption of a Gumbel distribution is used for reasons of analytic convenience, mainly due to the availability of an explicit formulation of the probability ($Probability_{powertrain\ i}$) associated with it. The Gumbel distribution is not a major limitation of this approach and can be defended as an approximation of the normal distribution. On the other hand, the assumption of independently and identically distributed disturbances may be a more important restriction, especially for innovative technologies, since there could be elements not included in the deterministic component of the utility (e.g. the range) that influence the consumers' choice for one technology option rather than another in different ways.

The influence of the technology availability on the market is taken into account combining the choices resulting from the application of the choice model (i.e. the probabilities discussed earlier) with exogenous inputs that need to represent the level of the expected technology availability at a given moment in time:

$$\begin{aligned}
 & \text{Share}_{\text{powertrain } i} \text{ in the new vehicle registrations} = \\
 & = \frac{\text{Technology Availability}_{\text{powertrain } i} \times \text{Probability}_{\text{powertrain } i}}{\sum_{\text{powertrains}} \text{Technology Availability}_{\text{powertrain } j} \times \text{Probability}_{\text{powertrain } j}} \\
 & = \frac{\text{Technology Availability}_{\text{powertrain } i} \times \frac{e^{\mu V_i}}{\sum_{\text{powertrains}} e^{\mu V_j}}}{\sum_{\text{powertrains}} \left(\text{Technology Availability}_{\text{powertrain } j} \times \frac{e^{\mu V_j}}{\sum_{\text{powertrains}} e^{\mu V_z}} \right)}
 \end{aligned}$$

The deterministic component of the utility is expressed in the model by the cost savings characterizing a given technology option over the vehicle life (also taking into account the influence of the discount rate selected by the user for expenditures that take place in the future, assuming that the average vehicle travel and the average cost of fuels in the future remain constant) in comparison with the same sort of cost, calculated for the most expensive technology.

Determination of the parameter μ with base year data

Base year data concerning technology availability, powertrain shares of newly registered vehicles and the deterministic component of the utility for each powertrain option are used in the model to calibrate the scale parameter μ . The base year endogenous inputs, needed to determine this scale parameter and coming from other views, include the following:

- "ENERGY CONS PER KM BY AGE (BASE YR)" (age ZERO) from the view "energy cons by age", i.e. the energy consumption per km of the new registrations at the base year;
- The variable "AVERAGE VEHICLE LIFE BY VCLASS (BASE YR)", a user input that was already introduced in the view "vehicles, new registrations (historical)";
- "COST OF FUEL PER UNIT ENERGY BY PWTRN (BASE YR)", calculated in the view "cost of driving" by means of user inputs and the fuel blend and powertrain matching matrix;
- The annual travel per vehicle at the base year: "ANNUAL KM PER VEH BY AGE (BASE YR)" (age ZERO), from the view "travel per vehicle by age", used to provide the annual travel of vehicles registered at the base year;
- The purchase price of the vehicles at the base year, taken from the initial value of the variable "COST/VEH BY PWTRN" from the view "vehicle costs (input)";
- The variable "NEW REGS (EXCL NMT AND PIPES) BY AGE (BASE YR)" (age ZERO) from the view "vehicles by age", used to determine the powertrain shares in the new vehicle registrations at the base year:

$$\text{Share}_{\text{powertrain } i} = \frac{\text{New registrations (age ZERO)}_{\text{powertrain } i}}{\sum_{\text{powertrains}} \text{New registrations (age ZERO)}_{\text{powertrain } j}}$$

- The initial value of the variable "INPUT ON POWERTRAIN SHARES/AVAILABILITY BY VCLASS, NEW REGS (INCLUDING 0/1 INPUT FOR NMT, AIR AND PIPELINES" from the view "vehicles, powertrain shares (input)", which provides the technology availability at the base year when the powertrain selection is treated endogenously.

Exogenous inputs that are necessary for the calculations of the scale parameter μ include:

- The discount rate, entered in the ForFITS Excel file ("Modelling switches") and enabling to differentiate the weight of expenditures taking place over time on the utility according to the equation:

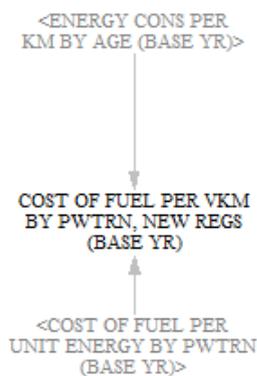
$$\text{Discount rate effect by age} = \frac{1}{(1 + \text{Discount rate})^{\text{age}}}$$

For instance, if the discount rate is 15 %, the expenditures at age zero are weighted by a factor of 1, the expenditures at age one are weighted by a factor of 0.87, and so on.

In some cases (e.g. when a single technology is used on a vehicle), the available data may not enable to calculate μ . Taking into account that the scale parameter is proportional to the inverse of the mean deviation of the disturbances from the mean value of their Gumbel distribution (σ)², μ is set, in these cases, in a way that corresponds to percentage of the total discounted cost estimated corresponding to the exogenous input "% OF THE TOTAL DISCOUNTED VEH & FUEL COST CORRESPONDING TO THE MEAN DEVIATION OF DISTURBANCES FOR THE TECHNOLOGY CHOICE", assumed by default to be 10%.

Detailed information on the calculation of μ

Figure 18.4 Cost of fuel per vkm



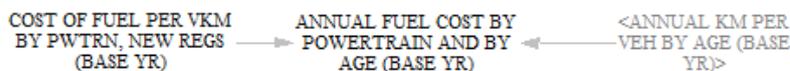
The energy consumption per km (litres/vehicle*km) of vehicles registered at the base year (age ZERO) multiplied by the cost of fuel per unit energy (USD/litre) provides the cost of fuel per vkm (Figure 18.4).

The annual expenditure on fuel consumption is the result of the product between the cost of fuel per vkm and the annual travel per vehicle at each age of the vehicle (Figure 18.5):

$$\text{Annual expenditures by age} = \text{Cost of fuel per vkm} \times \text{Annual travel by age}$$

The cost of fuel per vkm is assumed to remain the same as at the time when the vehicle is purchased.

Figure 18.5 Annual expenditure on fuel consumption



² $\mu = \frac{\pi}{\sigma \times \sqrt{6}}$. As mentioned at the beginning of the inputs section, the utility is the sum of a deterministic component and an unknown disturbance. The growth of the scale parameter means that the mean value of the unknown disturbances becomes increasingly negligible with respect to the value of its deterministic component. This leads to a choice that is increasingly characterised by the deterministic component of the utility. On the other hand, a decreasing value of μ implies that the mean deviation of the distribution of the disturbances tends to grow, increasing also the mean magnitude of the disturbances with respect to the value of the deterministic component of the utility. This results in a decreasing relevance of the deterministic component of the utility for the choice of one option rather than another. In this case, all choices tend to have the same probability of being selected because they are increasingly influenced by the non-deterministic component.

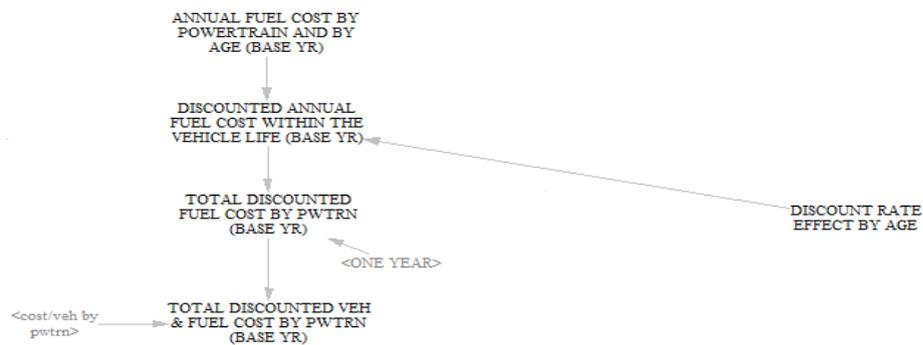
The total discounted fuel cost is calculated summing up the annual expenditures weighting by the corresponding discount rate factor at each age:

$$\text{Total discounted fuel cost} = \sum_{\text{ages within vehicle life}} \text{Expenditures}_{\text{age } i} \times \text{Discount rate}_{\text{age } i}$$

The total discounted cost is calculated adding the purchase price of the vehicle (consumer expenditure for the vehicle purchase), weighted by a discount rate factor of 1 (because it is assumed to take place at age zero) (Figure 18.6):

$$\text{Total discounted cost} = \text{Total discounted fuel cost} + \text{Purchase cost of the vehicle}$$

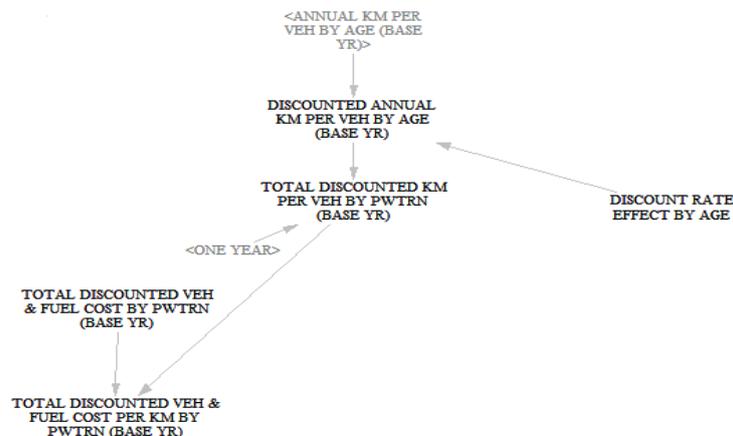
Figure 18.6 The total discounted cost



The relevant cost for the evaluation of the utility of each powertrain is the cost per km. This is calculated dividing the total discounted cost by the travel of the vehicle during its life (the annual travel at each age subscript is weighted by the corresponding discount rate factor) (Figure 18.7):

$$\text{Total discounted cost per km} = \frac{\text{Total discounted cost}}{\sum_{\text{ages within vehicle life}} \text{Annual travel}_{\text{age } i} \times \text{Discount rate}_{\text{age } i}}$$

Figure 18.7 Powertrain cost per km



The utility of a particular technology is defined as the difference between its cost per km and the cost per km of the most expensive powertrain, i.e. as the savings made if that particular technology is selected instead of selecting the most expensive one.

In order to avoid errors due to the order of magnitude of the numbers involved in the calculations (and taking into account that this has no effect on the results), the utility in ForFITS has been defined as follows:

$$Utility_{powertrain_i} = Cost\ per\ km\ of\ the\ cheapest\ technology - Cost\ per\ km\ powertrain_i$$

This means that the utility will be always negative, except for the cheapest powertrain where will be zero, representing the additional expenditures when selecting a specific technology compared to the cheapest powertrain option.

The isolation of μ results from the application of the equation combining the logit-based choices with inputs that represent the level of technology availability to the most widely used powertrains: GASOLINE PI ICE and DIESEL CI ICE:

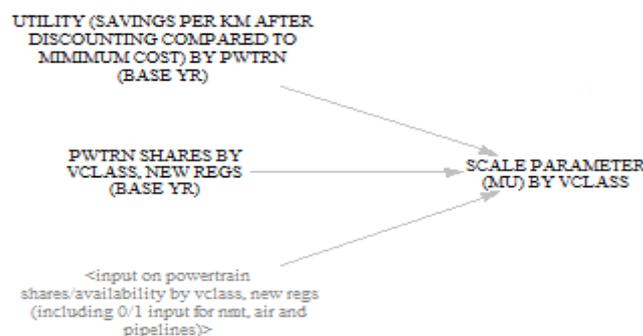
$$Share_{GASOLINE\ PI\ ICE\ in\ the\ new\ vehicle\ registrations} = \frac{Technology\ Availability_{GASOLINE\ PI\ ICE} \times \frac{e^{\mu V_{GASOLINE\ PI\ ICE}}}{\sum_{powertrains} e^{\mu V_j}}}{\sum_{powertrains} \left(Technology\ Availability_{powertrain\ j} \times \frac{e^{\mu V_j}}{\sum_{powertrains} e^{\mu V_z}} \right)}$$

$$Share_{DIESEL\ CI\ ICE\ in\ the\ new\ vehicle\ registrations} = \frac{Technology\ Availability_{DIESEL\ CI\ ICE} \times \frac{e^{\mu V_{DIESEL\ CI\ ICE}}}{\sum_{powertrains} e^{\mu V_j}}}{\sum_{powertrains} \left(Technology\ Availability_{powertrain\ j} \times \frac{e^{\mu V_j}}{\sum_{powertrains} e^{\mu V_z}} \right)}$$

$$\mu = \frac{-1}{(V_{DIESEL\ CI\ ICE} - V_{GASOLINE\ PI\ ICE})} \times \ln \left(\frac{Availability_{DIESEL\ CI\ ICE} \times Share_{GASOLINE\ PI\ ICE}}{Availability_{GASOLINE\ PI\ ICE} \times Share_{DIESEL\ CI\ ICE}} \right)$$

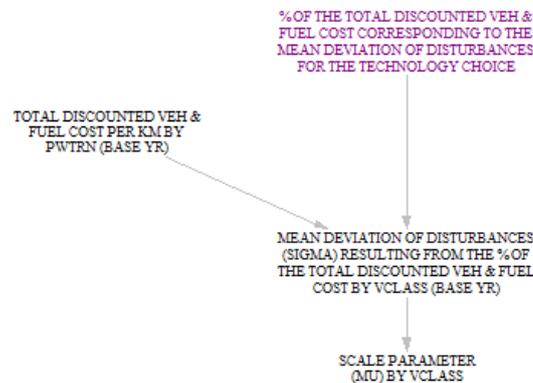
This allows calibrating the scale parameter μ from data on new registrations at the base year concerning technology shares, utility by powertrain and technology availability (Figure 18.8).

Figure 18.8 Calibration of the scale parameter μ : Vensim sketch



When the data available at the base year do not enable to calculate μ (e.g. because the GASOLINE PI ICE or the DIESEL PI ICE are zero), μ is set in a way that corresponds to assuming a mean value of the disturbances equal to a percentage of the total discounted cost derived from a 10% default assumption (Figure 18.9).

Figure 18.9 Default scale parameter μ : Vensim sketch



Outputs

Calculation of the powertrain shares over time

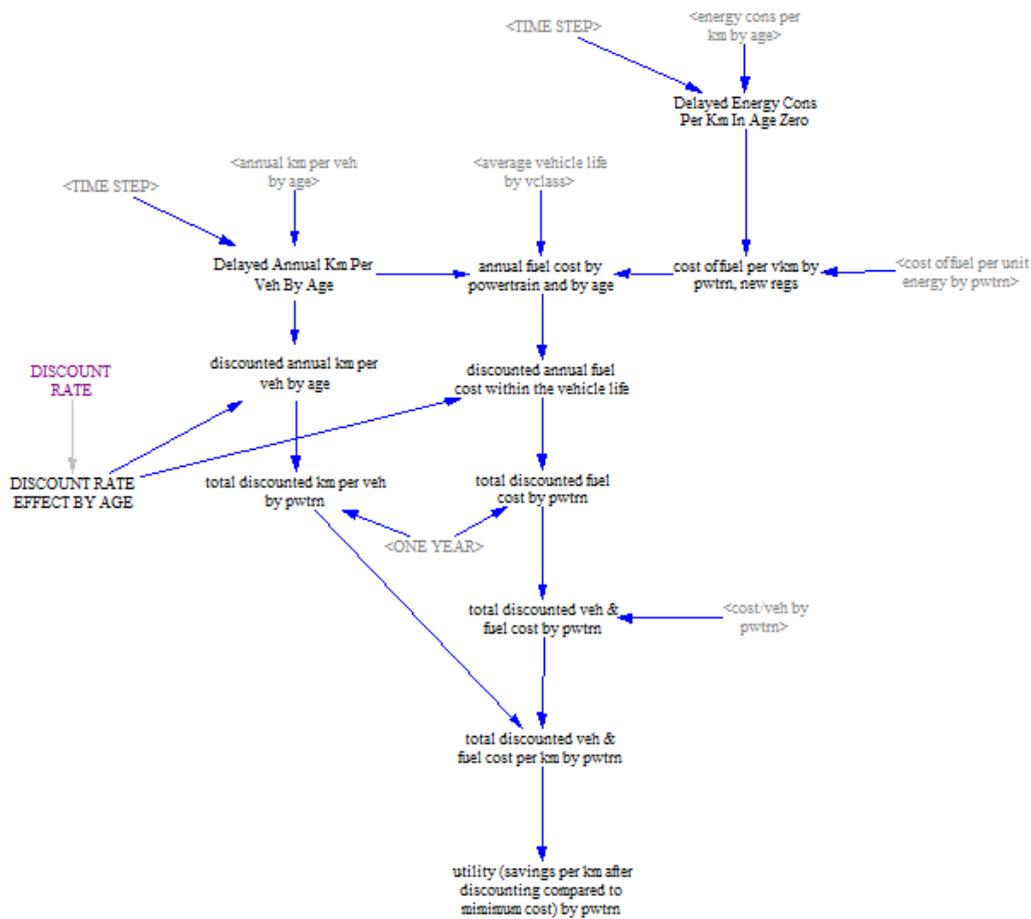
The main aim of the view is to determine the powertrain shares in the new vehicle registrations over time by means of the logit model. The structure on the left half of the view is reproduced in the right half (Figure 18.10). The endogenous information used in this section of the view include:

- "ENERGY CONS PER KM BY AGE" (age ZERO), from the view "energy cons by age", i.e. the energy consumption per km of the new registrations over time;
- "AVERAGE VEHICLE LIFE BY VCLASS", calculated in the view "vehicles, new registrations (historical)" and set by default to be the same as the user input at the base year;
- "COST OF FUEL PER UNIT ENERGY BY PWTRN", calculated in the view "cost of driving" by means of user inputs and the fuel blend and powertrain matching matrix;
- "ANNUAL KM PER VEH BY AGE" (age ZERO), from the view "travel per vehicle by age", providing the annual travel of new vehicle registrations over time;
- The purchase cost of the vehicles over time, contained in "COST/VEH BY PWTRN", from the view "vehicle costs (input)";
- "INPUT ON POWERTRAIN SHARES/AVAILABILITY BY VCLASS, NEW REGS (INCLUDING 0/1 INPUT FOR NMT, AIR AND PIPELINES)", from the view "vehicles, powertrain shares (input)", with information on the technology availability over time.
- The scale parameter μ , assumed to maintain the same value as in the base year.

The methodology used is exactly the same as what was described to calibrate μ , but now the scale parameter is an input while the powertrain shares are the outputs.

The deterministic component of the utility for each powertrain over time is calculated accordingly to the same procedure detailed for the base year (Figure 18.10).

Figure 18.10 Vensim sketch: zoom on the calculations of variables changing over time



The powertrain shares in new vehicle registrations over time from the scale parameter and the inputs over time characterizing i) the utility by powertrain and ii) the technology availability (Figure 18.11):

$$Share_{powertrain\ i\ in\ the\ new\ vehicle\ registrations} = \frac{Technology\ Availability_{powertrain\ i} \times \frac{e^{\mu V_i}}{\sum_{powertrains} e^{\mu V_j}}}{\sum_{powertrains} \left(Technology\ Availability_{powertrain\ j} \times \frac{e^{\mu V_j}}{\sum_{powertrains} e^{\mu V_z}} \right)}$$

Figure 18.11 Vensim sketch: powertrain shares in new vehicle registrations over time

