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The SNOW Model for Norway

Documentation of SNOW-NO

TALL SOM FORTELLER

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Preface

This document provides a description of the SNOW model for Norway (SNOW-NO), a multi-sector computable general equilibrium (CGE) model tailored to analyze energy, environmental and climate policies in Norway. The development of the SNOW model and the preparation of this have been supported by funding from the Ministry of Finance.

Statistisk sentralbyrå, 18 February 2024

Linda Nøstbakken

Abstract

In this document, we provide a description of the SNOW model for Norway (SNOW-NO), a multi-sector computable general equilibrium (CGE) model tailored to analyze energy, environmental and climate policies in Norway. The document includes an explanation of how parameters and variables are quantified for the current base year (2018) and in business-as-usual (BAU) projections until 2030, in addition to presenting an algebraic model description.

Contents

1. Introduction

The Statistics Norway's World (SNOW) models constitute a family of different model variants, including a global version (SNOW-GLO), a small open economy version for Norway (SNOW-NO) and an intertemporally dynamic version (SNOW-DYN).[1] This documentation mainly describes the SNOW model for Norway (SNOW-NO). This includes the description of how parameters and variables are quantified in the current base year (2018) and in business-as-usual (BAU) projections until 2030. SNOW-NO is a multi-sector computable general equilibrium (CGE) model for the Norwegian economy. Norway is modelled as a small, open economy, implying that the rest of the world is treated as exogenous. The model describes market interactions among all agents of the economy (industries, households and government), as well as cross-border trade interactions.

The model assumes optimising agents: producers maximise profits and a representative household maximises welfare. The household receives all income from the primary factors labour, capital, and natural resources. The public sector receives all tax revenues and pays out subsidies to industries and transfers to the household. The model finds equilibrium prices and quantities by simultaneously solving a set of equations that satisfy the profit-maximisation and welfare-maximisation conditions. This system determines annual production, consumption, export and import levels for all goods, input use in each industry, domestic prices of all goods and input factors (labour, capital and energy resources), and greenhouse gas emissions in the economy. SNOW-NO is a recursive-dynamic model in which each individual year is linked to previous years via households' savings decisions and companies' investment decisions.

An earlier version of the SNOW-NO model is documented in Rosnes et al. (2019), who give a detailed description of the modelling of taxes.

[1] Recent analyses using SNOW-GLO include Fæhn and Yonezawa (2021), Kaushal et al. (2023) and Bye et al. (2022). Recent analyses using SNOW-NO includes Bye et al. (2023), Fæhn et al. (2020), Kaushal et al. (2019), Kaushal and Yonezawa (2022), Fæhn et al. (2021), and Bye et al (2021).

2. Overview of SNOW-NO

2.1. Production

There is one representative producer in each production sector that minimizes costs for each period. The model consists of 46 production sectors (see Table 2.1) that are assumed to produce one good each.

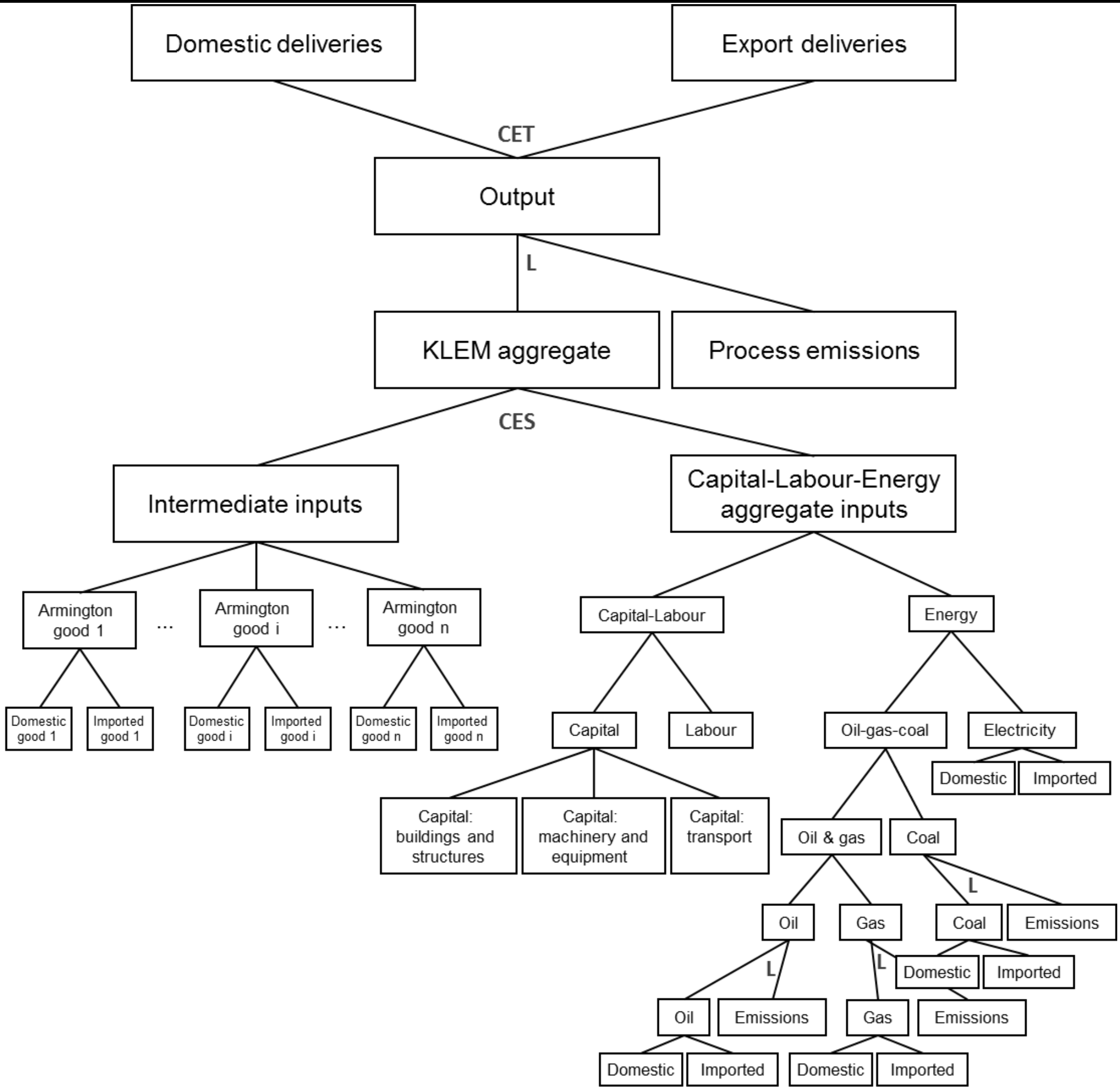
The production technologies are described by nested Constant Elasticity of Substitution (CES) functions that capture the combinations of capital, labour, energy and intermediate products in each industry.[2] Substitution possibilities between different inputs in a given industry are represented by a constant elasticity of substitution (CES), which determines how the optimal use of inputs changes as the relative prices change. The larger the value of the elasticity, the easier it is to substitute one input for another. The demand for input factors follows from the assumption of cost minimising producers. It is possible to specify different substitution elasticities at all levels in the CES function, and the model user can set the substitution elasticities that are considered relevant. All prices are real prices, as the model has the consumer price index as numeraire.

For most commodities, the combination of capital, labour, energy and intermediate products that is used in production can change, depending on prices. For most of the industries, Figure 2.1 depicts the structure of inputs. (The resource-based industries and the land transport sector deviate slightly; see Section 1.1.1 and 1.1.2). At the top level, a CES aggregate of intermediate material demand trades off with an aggregate of energy, capital and labour. At the second level, a CES function describes the substitution possibilities between intermediate demand for the energy aggregate and a value-added aggregate of labour and capital. At the third level, capital and labour substitution possibilities within the value-added aggregate are captured by a CES function, whereas different energy inputs (coal, gas, oil and electricity) enter the energy aggregate.

Labour and capital are perfectly mobile between sectors, implying that capital is perfectly malleable, i.e., investments can take place gradually. Capital consists of three types: building and construction, machinery and equipment, and means of transport. The availability of capital is given in the base year and then changes with the domestic investments, which in turn are determined by the savings of the households in each period. In an optional version of the model, capital can also move across borders, so that investments are influenced by both domestic and foreign interest rates. Total access to labour is endogenous and determined by the household's choice of labour or leisure.

[2] The nested CES function (Varian, 1992) is standard in CGE models. The functions nest inputs and quantify their use according to values for substitution elasticities and share parameters.

Figure 2.1 Production technology (nested CES structure) of most goods. L denotes nests with Leontief structure, i.e. no substitution possibilities.



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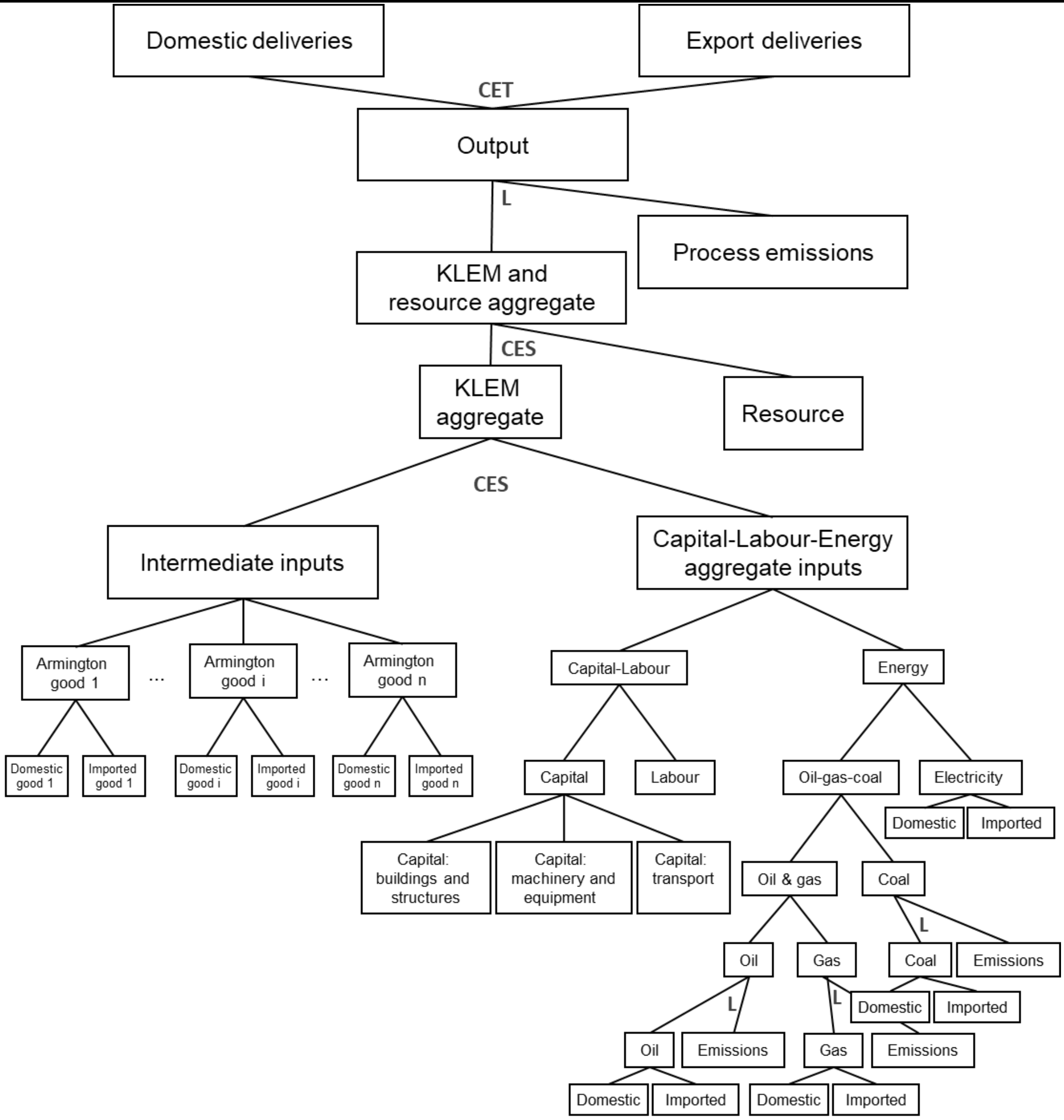
2.1.1. Resource-based industries

The production of fossil fuels (extraction of coal, oil and gas) and other resource-based production (electricity and agriculture) is modelled differently from other sectors (see Figure 2.2) as these sectors use sector-specific natural resources, provided in fixed amounts, so there is no substitutability between the resource and the other inputs (labour, capital, energy and intermediates).This modelling allows for managing the development of these industries by setting the amount of the sector-specific resource.

Figure 2.2 Production technology (nested CES structure) for resource-based goods. L denotes nests with Leontief structure, i.e. no substitution possibilities



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2.1.2. The land transport sector

The Land transport (OTP) production sector includes a substantial share of the commercial transportation activities in the Norwegian economy. To reflect this, a driving-related component is explicitly modelled in its CES nesting structure (See Figure 2.3 and Figure 2.4). Similarly to the private driving of households, we consider four different types of vehicles (i.e., new vs. old cars and ICE cars vs. EVs). The sales share and stock share of EVs in 2018 and 2021 are calibrated with the real data of vans. With the same assumptions on substitution elasticities and EV import price projections, the demand and supply of vehicles in OTP are determined endogenously in the BAU scenario.

Figure 2.3 Production technology (nested CES structure) for the OTP sector

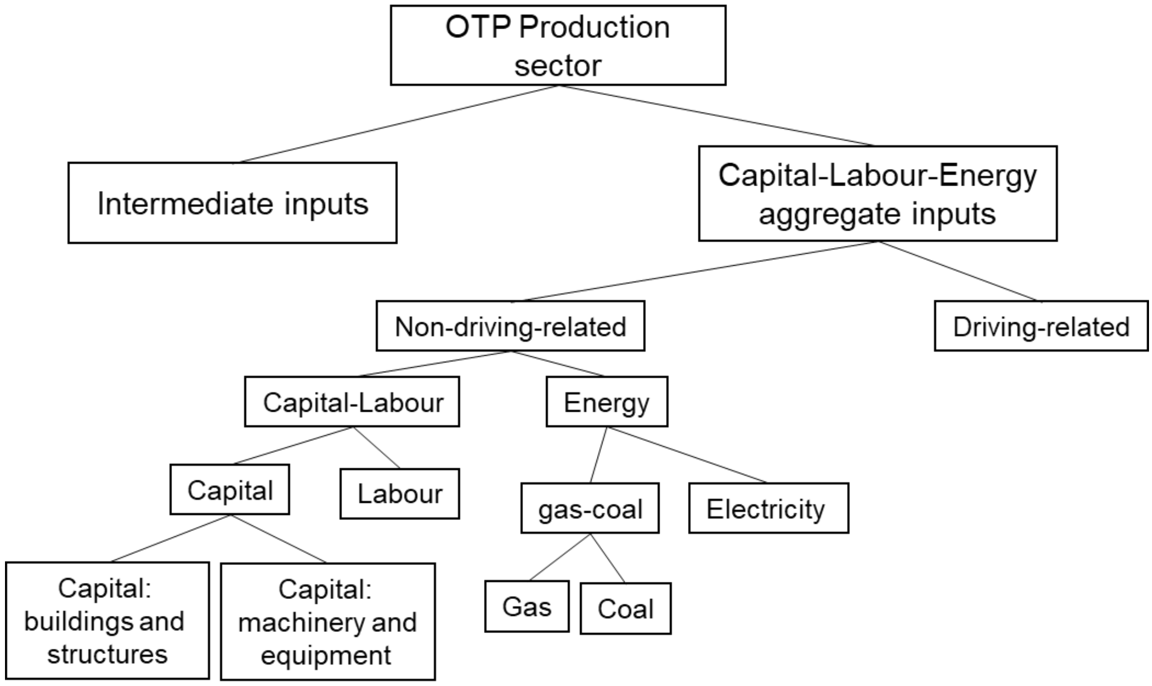

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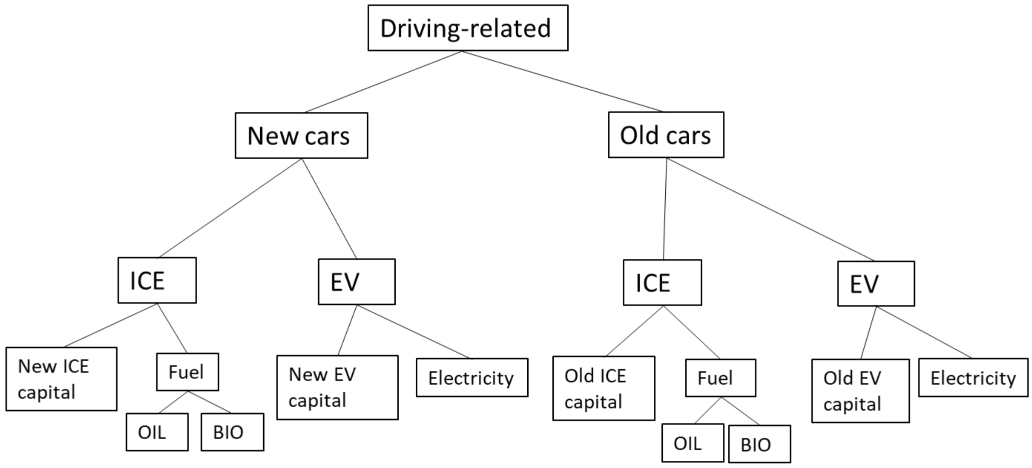
Figure 2.4 Nested CES structure for driving related activity in the OTP



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2.2. Trade

We model a small, open economy, which by assumption cannot affect the world market conditions. Thus, world market prices are exogenous. All goods used in the domestic markets for intermediate and final goods consist of substitutable imported and domestically produced varieties, combined in CES composites. The CES elasticities denoted Armington elasticities (Armington, 1969) reflect heterogeneity; the lower the Armington elasticity the more heterogeneous are the imported and domestic varieties considered by the demanders. Correspondingly, export is determined by a Constant Elasticity of Transformation (CET) function between domestic and export market deliveries. This implies an implicit adjustment cost of reallocating deliveries between the domestic and export market: the lower the CET elasticity, the higher the adjustment cost (the less substitutable are the markets considered by the supplier).

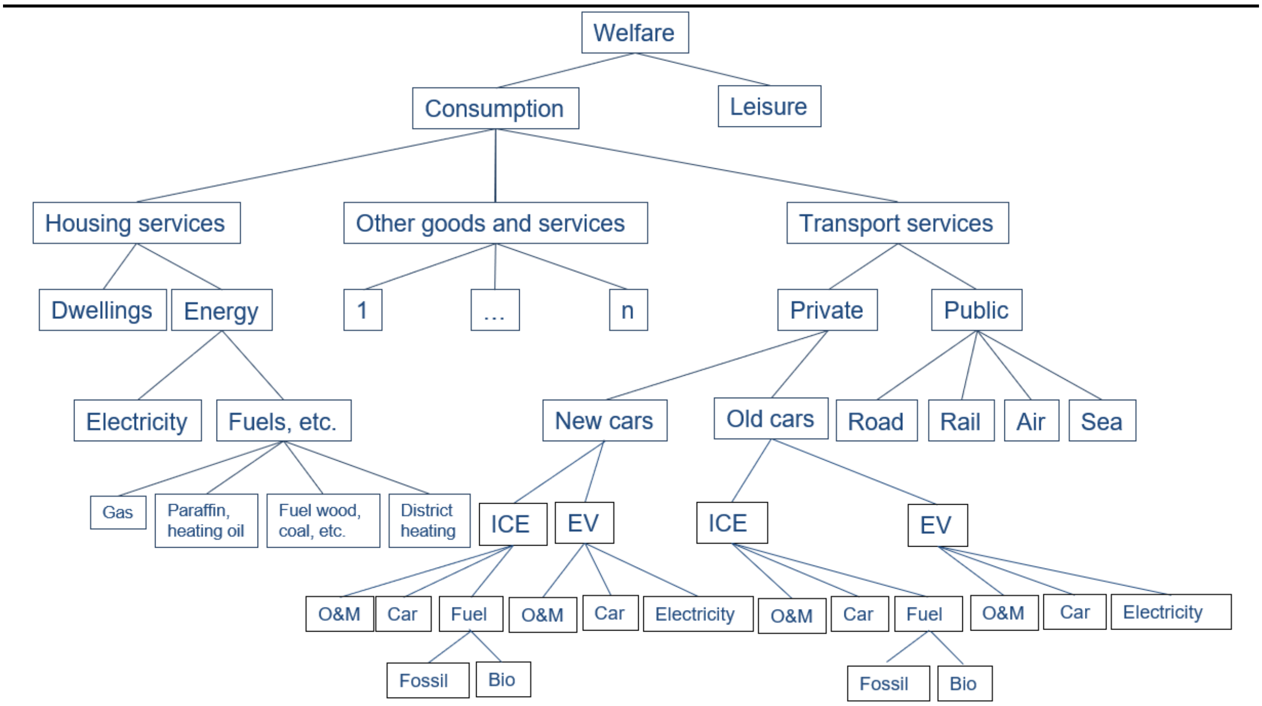
Factor prices and prices of domestic deliveries are all determined by domestic market equilibrium. Together with a given balance of payments, the real exchange rate, which is consistent with domestic consumption, will be determined (Horridge et al., 2013). In addition to net exports of goods and services, trade in emission quotas from the EU ETS, payments to and withdrawals from the SPU, development aid and other international capital movements are also included in the operating balance.

2.3. Households

The model features a representative household that receives income from labour, capital and natural resources, and tax revenues (net of subsidies). Final consumption and leisure demand are determined by the representative household who maximizes welfare subject to a budget constraint. Savings and government provision of public goods and services are exogenous.

Figure 2.5 shows the household demand system that is modelled by a nested CES preference structure (Varian, 1992). At the top level, the CES function describes substitution between the consumption aggregate and leisure. At the second level, we find the aggregates of housing services, other goods and services and transport services. At the third level, CES functions describe three main aggregates: i) dwellings and energy used in housing services; ii) the private and public transport composite; iii) all other goods and services. The fourth level shows the substitutability between energy sources within the energy composite, between old and new cars in private transport, and between the different means of public transport. Substitution possibilities between different goods are represented by substitution elasticities (see section 2.5.3).

Figure 2.5 Welfare function of the representative consumer (nested CES-structure)



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2.3.1. Quantification of leisure

Regarding the quantification of leisure and the elasticity of substitution between leisure and material consumption, we follow the derived equations from a theoretical model in Yonezawa (2013), which is based on Ballard (2000). In this way, we do not determine the quantity of leisure by counting the number of total available hours. Instead, we calculate it by using the data in the input-output table of Norway and empirically estimated parameters. The advantage of quantifying the leisure from a theory-based formula is that we avoid making arbitrary choices related to total available hours, such as: how many hours that should be devoted to sleep, non-sleeping and non-working hours, holidays and so on. The derivation of the following equations can be found in Yonezawa (2013).

The derived share of leisure (*LE*) out of total time endowment L_{shr} is a function of material consumption (*C*), labour supply (*LS*), and compensated and uncompensated labour supply elasticities (ε_{com} and ε_{un}):

$$L_{shr} = \frac{LE}{LE + LS} = \frac{C(\varepsilon_{com} - \varepsilon_{un})}{LS(1 - \varepsilon_{com} + \varepsilon_{un}) + C(\varepsilon_{com} - \varepsilon_{un})}$$

The elasticity of substitution between leisure and consumption is calculated by the following equation:

$$\sigma^{CL} = \frac{LS\ \varepsilon_{com}}{C(\varepsilon_{com} - \varepsilon_{un})}$$

We use the following labour supply elasticities with respect to wage:

- Compensated labour supply elasticity (ε_{com}): 0.50
- Uncompensated labour supply elasticity (ε_{un}): 0.20

The compensated labour supply elasticity is taken from Chetty (2012), whereas the uncompensated labour supply elasticity is based on the ones in the LOTTE-Arbeid model (see Apps et al., 2020 and Thoresen and Vattø, 2015) Specifically, based on estimates of uncompensated elasticities of 0.13 for single individuals, 0.49 for women in couples and 0.10 for men in couples, we assume the average uncompensated elasticity is 0.20 (i.e. about a quarter of the workforce is married women).

With these values and the consumption and labour supply values in the input-output table of Norway of 2018, we calculate the following parameters by using equations above:

- The share of leisure out of total time endowment (L_{shr}): 0.40
- The elasticity of substitution between material consumption and leisure (σ^{CL}): 1.1

The direct interpretation of the leisure share is that we (or rational households following the microeconomic theory model) allocate about 40 percent of the available time to leisure if we use the labour supply elasticities above, consumption and net-of-tax labour supply value from the input-output table of 2018.

Even though the leisure quantity is not directly calculated from the total number of available hours, the quantified leisure share (40%) corresponds to 1198 hours of leisure out of 3029 available hours per year if we assume that 233 days (net of holidays and weekends) times 16 hours per day (net of sleeping, eating and other necessary chores) as an example. With the same assumption, if we think of a normal working day, it corresponds to 5 hours leisure and 8 hours work per day.

2.3.2. Private driving

Private driving consists of driving new cars (purchased in the same period) and old cars (purchased in previous periods). We consider two types of cars: conventional internal combustion engine vehicles (ICEs) and electric vehicles (EVs). Normal hybrids are classified as ICE as they use only petrol/diesel, and thus they are simply more efficient ICEs. Plug-in hybrids (PHEV) are not taken into account in the model. Accordingly, the car-related operational and maintenance expenses (e.g., energy cost, insurance, service); see O&M Figure 2.5, are associated with the stock of the cars.

The representative household's spending on cars consists of expenditures for motor vehicles (including parts), retailer's service fee, and all other service costs. In the CES nesting structure, the activity of private driving is split into the use of old and new cars, which in turn are split into EVs and ICEs (see Figure 2.5).[3] Thus, we keep track of both old cars (purchased before the current year in the simulation) and new cars (purchased in the current year). The modelling of private vehicles in SNOW is calibrated to the development of the stocks from 2018 (base year) to 2021. Consumption of fuel (both fossil and bio) and electricity is based on the stock of old and new cars.

Expenses for new cars and old cars are modelled as annual rental values. Thus, when consumers choose EVs or ICEs, they consider the annual expenses consisting of annual rental values, fuel or electricity costs, and O&M costs for each type of car. The elasticity of substitution between EVs and ICEs captures the substitutability between the two types of new cars; i.e., an increase in this elasticity means that the attributes of EVs and conventional cars have become more similar. In other words, it will be easier to switch from conventional cars to EVs in future years. The exogenous price of imported EVs is assumed to decrease by 5% each year from 2019 to 2024 and by 2.5% from 2025 to 2030.

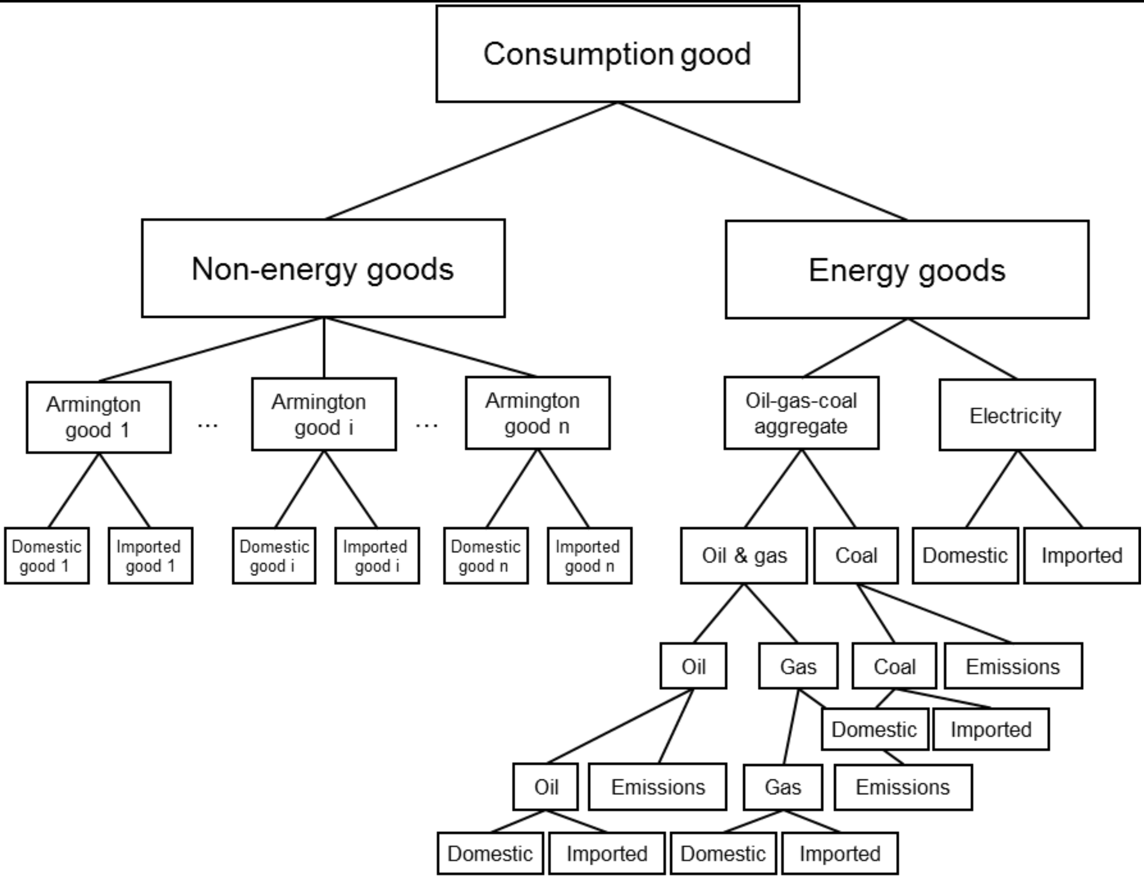
To match the BAU information on EV phase-in for the projection period (2019 to 2030), three variables are treated as calibration instruments: the substitution elasticity, the import price of EVs and the implicit non-fiscal advantages given to EV users are treated as calibration instruments. The implicit subsidy represents the advantages of EVs that are not modelled (e.g., discounted parking, access to bus lanes, cheaper toll roads etc.) and the improved attributes of the EVs ("more car for the same price"). In any counterfactual simulations we fix the substitution elasticity, the import prices and the implicit subsidy at the business-as-usual level (BAU), so that the EV sales share becomes endogenous.

On the supply side, domestic production and import of the good "motor vehicles including parts" (see section 1.6, Table 2.1) is split into conventional ICE vehicles and EVs, respectively. Note that Norwegian production of private vehicles and parts is small.

Final consumption goods are modelled as CES functions of output from the industries in shares given by the I-O table in the base year, i.e., the CES substitution elasticities are equal to zero); see Figure 2.6. The list of final consumption goods is included in Table 2.2.

[3] A similar structure is modelled by Karplus et al., 2010 and Chen et al., 2017. Bjertnæs et al. (2011) also develops a similar structure, although it is not in an economy-wide model but in a model of private consumption.

Figure 2.6 Production of final consumption goods (nested CES structure)



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2.4. Emissions

We model emissions of the six Kyoto greenhouse gases: CO_2, CH_4, N_2O and the fluorinated greenhouse gases SF_6, KFK and HFK. In addition, SO_2, NOX, CO, NH_3, NMVOC and particles (PM), which are pollutants with regional and local impacts, are modelled. The emissions are measured in tons. The Kyoto gases are converted to tons of CO_2 equivalents according to their global warming potential (GWP 100). Emissions are either modelled as energy-related or as originating from industrial processes. Energy-related emissions are linked in fixed proportions to the use of fossil fuels, with emission coefficients differentiated by the specific carbon content of fuels (see Figure 2.1 and Figure 2.2). Abatement can take place by fuel switching, electrification, substitution of other goods for energy, or by scaling down production and/or final consumption. Emissions from industrial processes are linked to the output of the sector. Abatement of process emissions within existing production technologies can only take place by reducing output.

2.5. More on data and calibration

Main input data are the input-output tables in the Norwegian National Accounts and emission data from Statistics Norway. The classification of industries is based on the standard GTAP classification[4] (Narayanan et al., 2012), but adjusted to Norwegian data availability and relevance. The list of industries is included in Table 2.1. The classification of final consumption goods is based on Norwegian National Accounts, see Table 2.2.

[4] https://www.gtap.agecon.purdue.edu/

For model parameterisation, we follow the standard calibration procedure for applied general equilibrium analysis: the base-year (2018 in this version) input-output data determine the free parameters of the cost and expenditure functions, so that the economic flows represented in the data are consistent with the optimizing behaviour of the model agents.

All quantities (except emissions) are measured in money-metrics, i.e. the expenditures in fixed base-year prices; this also applies to energy use. The model is developed in GAMS/MPSGE (GAMS, 2014; Rutherford, 1999).

Quantification of the remaining substitution elasticities not presented above, is based on pertinent econometric literature. The GTAP database provides substitution possibilities in production (between primary factor inputs), with most substitution elasticities in the range of 0–1 (Narayanan et al., 2012). The current model assumes uniform elasticities across most industries. The estimates of elasticities can be changed depending on the analytical design and focus. For example, one way of exogenising the activities of a sector using an exogenous natural resource can be to set substitution elasticities to zero, implying fixed proportional inputs. The elasticities of substitution in fossil fuel sectors are calibrated to match exogenous estimates of fossil fuel supply elasticities (Graham, Thorpe and Hogan 1999; Krichene 2002; Okagawa and Ban, 2008). The substitution elasticities in the household model are set to 0.5. The background is findings in Andreassen and Bjertnæs (2006) that most substitution elasticities lie in the range 0-1. The relation between emissions and other inputs are fixed. Elasticities in international trade are based on the GTAP database and McDaniel and Balistreri, (2002).

Table 2.1 Industries in SNOW-NO

Agriculture	AGR
Forestry	FRS
Fishing	FSH
Coal production	COA
Oil & gas extraction	CRU
Minerals nec	OMN
Food products – meat	MEA
Vegetable oils and fats	VOL
Dairy products	MIL
Food products nec	OFD
Beverages and tobacco products	B_T
Textiles	TEX
Wearing apparel	WAP
Leather products	LEA
Wood products	LUM
Paper products, publishing	PPP
Petroleum, coal products except biofuels	OIL
Biofuels	BIO
Chemical, rubber, plastic products	CRP
Mineral products nec	NMM
Ferrous metals	I_S
Metals nec	NFM
Metal products	FMP
Motor vehicles and parts – conventional internal combustion engine (ICE) vehicles	MIE
Motor vehicles and parts – electric vehicles (EV)	MEV
Transport equipment nec	OTN
Machinery and equipment, incl. electronic equipment	MEE
Manufactures nec	OMF
Electricity	ELE
Gas manufacture, distribution	GAS
Water	WTR
Construction	CNS
Trade	TRD
Transport nec	OTP
Water transport	WTP
Air transport	ATP
Communication	CMN
Financial services nec	OFI
Insurance	ISR
Business services nec	OBS
Recreational and other services	ROS
Public sector (defence)	OSG*
Dwellings	DWE
Public sector – central government (administration, education, health services, culture)	OSS*
Public sector – local government (admin., education, health services, culture, water)	OSK
Private education and health services	OSP*
Waste management (private)	AVP*
Waste management (public)	AVK*

Table 2.2 Final consumption in SNOW-NO

Food and non-alcoholic beverages	CFAB
Alcoholic beverages and tobacco etc.	CABT
Clothing and footwear	CCAC
Housing & water	CHAW
Electricity (for heating)	CELE
Gas (for heating)	CGAS
Paraffin and heating oil (for heating)	CPAH
Fuel wood, coal etc. (for heating)	CFAC
District heating	CDHE
Furnishings, household equipment and routine household maintenance	CFHR
Health	CHEA
Transport equipment – conventional internal combustion engine (ICE) vehicles	CTEQ
Transport equipment – electric vehicles (EV)	CTEV
Fuel in private transport – Petrol & diesel including biofuels	CPAD
Fuel in private transport – Electricity for EVs	CEEV
Public transport (rail)	CRAI
Public transport (road)	CROA
Public transport (air)	CAIR
Public transport (boat)	CBOA
Communication	CCOM
Recreation and culture	CRAC
Education	CEDU
Restaurants and hotels	CRAH
Miscellaneous goods and services	CRAH
Final consumption expenditure of central government	GS
Final consumption expenditure of local government	GK
Final consumption expenditure of NPISHs	GF
Gross fixed capital formation – private	I
Gross fixed capital formation – central government	IG
Gross fixed capital formation – local government	IG

3. Algebraic Model Description

The model equations are presented in blocks of price and demand equations, market clearance conditions and budget constraints. Production functions are not modelled explicitly, since all the necessary information is contained in the dual price functions.

In the following, the equations are presented in general form. In the numerical implementation, some CES-functions are reduced to Leontief or Cobb-Douglas functions (by setting elasticities of substitution to zero or one, resp.). The benchmark data determines the share parameters (θ)

All variables and parameters in this model description are listed in section 2.6.

For simplifications, emissions are not included in the equations below. However, they are simply combined with the exogenous proportion to the fossil fuel consumption (energy-related emissions) or production quantity (process emissions), see Figure 2.1 and 2.2.

3.1. Price equations

3.1.1. Production of most commodities

The production technologies of most commodities[5] are captured by nested constant elasticity of substitution (CES) cost functions, see Figure 2.1. Production functions are not modelled explicitly; instead, the dual price functions are modelled. These contain all the necessary information.

3.1.1.1. KLE vs. M

In the KLEM-nest, material aggregate (intermediate input from other industries) trades off with capital-labour-energy (KLE) aggregate:

$$\frac{P_{Y,i}(1-t_{Y,i})}{\bar{P}_{Y,i}(1-\bar{t}_{Y,i})} = \left[\theta_i^{KLE}\left(\frac{P_{KLE,i}}{\bar{P}_{KLE,i}}\right)^{1-\sigma_i^Y} + \theta_i^{MAT}\left(\frac{P_{MAT,i}}{\bar{P}_{MAT,i}}\right)^{1-\sigma_i^Y}\right]^{\frac{1}{1-\sigma_i^Y}}$$

3.1.1.2. Intermediate inputs

Intermediate inputs (Armington goods) from other industries *ii* (*ii* excludes energy goods) are partly substitutable with each other in production in industry *i*:

$$\frac{P_{MAT,i}}{\bar{P}_{MAT,i}} = \left[\sum_{ii\in NEN}\theta_{i,ii}^{A}\left(\frac{P_{A,ii}(1+t_{A,i,ii})}{\bar{P}_{A,ii}(1+\bar{t}_{A,i,ii})}\right)^{1-\sigma_i^{MAT}}\right]^{\frac{1}{1-\sigma_i^{MAT}}}$$

Input taxes ($t_{A,i,ii}$) may be applied for use of good ii in production of good *i*.

3.1.1.3. Armington: domestic vs. imported goods

Domestic and imported goods are imperfect substitutes that are combined into an "Armington good":

[5] Resource-based commodities (such as CRU, COA, GAS, AGR, ELE) includes resource factor input at the top nest as it is shown in 2.1.2.

$$\frac{P_{A,i}}{\overline{P}_{A,i}} = \left[\theta_i^{DA}\left(\frac{P_{DOM,i}}{\overline{P}_{DOM,i}}\right)^{1-\sigma_i^A} + \theta_i^{IMP}\left(\frac{P_{IMP,i}(1+t_{IMP,i})}{\overline{P}_{IMP,i}(1+\overline{t}_{IMP,i})}\right)^{1-\sigma_i^A}\right]^{\frac{1}{1-\sigma_i^A}}$$

3.1.1.4. KL vs. E

Capital-labour-aggregate trades off with energy aggregate with substitution elasticity σ_i^{KLE}:

$$\frac{P_{KLE,i}}{\overline{P}_{KLE,i}} = \left[\theta_i^{KL}\left(\frac{P_{KL,i}}{\overline{P}_{KL,i}}\right)^{1-\sigma_i^{KLE}} + \theta_i^{E}\left(\frac{P_{E,i}}{\overline{P}_{E,i}}\right)^{1-\sigma_i^{KLE}}\right]^{\frac{1}{1-\sigma_i^{KLE}}}$$

3.1.1.5. K vs. L

$$\frac{P_{KL,i}}{\overline{P}_{KL,i}} = \left[\theta_i^{K}\left(\frac{P_{K,i}}{\overline{P}_{K,i}}\right)^{1-\sigma_i^{KL}} + \theta_i^{L}\left(\frac{P_{L}(1+t_{L,i})}{\overline{P}_{L}(1+\overline{t}_{L,i})}\right)^{1-\sigma_i^{KL}}\right]^{\frac{1}{1-\sigma_i^{KL}}}$$

3.1.1.6. Capital varieties

Different types of capital (machinery and equipment, buildings and constructions, and transport equipment) are substitutes:

$$\frac{P_{K,i}}{\overline{P}_{K,i}} = \left[\sum_{KV\in\{KMA,KBA,KTR\}}\theta_i^{KV}\left(\frac{P_{KV}}{\overline{P}_{KV}}\right)^{1-\sigma_i^{K}}\right]^{\frac{1}{1-\sigma_i^{K}}}$$

Note that land transport (OTP) takes the transport-type capital (KTR) as car capital and put it under driving-related component.

3.1.1.7. The energy sub-nest:
Electricity (ELE) vs. non-electricity (NELE = oil, gas, coal)

$$\frac{P_{E,i}}{\overline{P}_{E,i}} = \left[\theta_i^{ELE}\left(\frac{P_{A,ELE}(1+t_{A,i,ELE})}{\overline{P}_{A,ELE}(1+\overline{t}_{A,i,ELE})}\right)^{1-\sigma_i^{E}} + \theta_i^{NELE}\left(\frac{P_{NELE,i}}{\overline{P}_{NELE,i}}\right)^{1-\sigma_i^{E}}\right]^{\frac{1}{1-\sigma_i^{E}}}$$

Oil and gas (LQD) vs. coal (COA)

$$\frac{P_{NELE,i}}{\overline{P}_{NELE,i}} = \left[\theta_i^{LQD}\left(\frac{P_{LQD,i}}{\overline{P}_{LQD,i}}\right)^{1-\sigma_i^{NELE}} + \theta_i^{COA}\left(\frac{P_{A,COA}(1+t_{A,i,COA})}{\overline{P}_{A,COA}(1+\overline{t}_{A,i,COA})}\right)^{1-\sigma_i^{NELE}}\right]^{\frac{1}{1-\sigma_i^{NELE}}}$$

Oil (OIL) vs. gas (GAS)

$$\frac{P_{LQD,i}}{\overline{P}_{LQD,i}} = \left[\theta_i^{OIL}\left(\frac{P_{A,OIL}(1+t_{A,i,OIL})}{\overline{P}_{A,OIL}(1+\overline{t}_{A,i,OIL})}\right)^{1-\sigma_i^{LQD}} + \theta_i^{GAS}\left(\frac{P_{A,GAS}(1+t_{A,i,GAS})}{\overline{P}_{A,GAS}(1+\overline{t}_{A,i,GAS})}\right)^{1-\sigma_i^{LQD}}\right]^{\frac{1}{1-\sigma_i^{LQD}}}$$

Note that some sectors (e.g., households, land transport and air transport) consider the split of refined oil (OIL) into conventional oil (OIL) and (BIO), and they are substitutable by following a CES function.

3.1.2. Production of resource-based goods

The production technologies of resource-based commodities[6] $xe \in \{CRU, COA, GAS\}$ are captured by nested constant elasticity of substitution (CES) cost functions, see Figure 2.2.

3.1.2.1. Top-level: KLEM vs. resources

Production of resource-based goods combines aggregate inputs of capital, labour and materials (KLEM) from other industries with the sector-specific resource R:

$$\frac{P_{Y,xe}(1-t_{Y,xe})}{\overline{P}_{Y,xe}(1-\overline{t}_{Y,xe})}=\left[\theta_{xe}^{KLEM}\left(\frac{P_{KLEM,xe}}{\overline{P}_{KLEM,xe}}\right)^{1-\sigma_{xe}^{Y}}+\theta_{xe}^{R}\left(\frac{P_{R,xe}(1+t_{R,xe})}{\overline{P}_{R,xe}(1+\overline{t}_{R,xe})}\right)^{1-\sigma_{xe}^{Y}}\right]^{\frac{1}{1-\sigma_{xe}^{Y}}}$$

For calibration of the elasticity of substitution between the specific resource and other inputs, see Rutherford (2002), p.6.

3.1.2.2. KLEM aggregate

In the KLEM-nest, all other inputs (capital, labour, energy goods and intermediate inputs from other industries, including energy goods) are aggregated with fixed coefficients.[7] The intermediate inputs of all goods are Armington aggregates, as defined above. Capital is an aggregate of different types of capital.

$$\frac{P_{KLEM,xe}}{\overline{P}_{KLEM,xe}}=\left[\sum_{KV\in\{KMA,KBA,KTR\}}\theta_{xe}^{KV}\left(\frac{P_{KV}}{\overline{P}_{KV}}\right)+\theta_{xe}^{L}\left(\frac{P_{L}(1+t_{L,xe})}{\overline{P}_{L}(1+\overline{t}_{L,xe})}\right)+\sum_{ii=1,\dots,n}\theta_{xe,ii}^{A}\left(\frac{P_{A,ii}(1+t_{A,xe,ii})}{\overline{P}_{A,ii}(1+\overline{t}_{A,xe,ii})}\right)\right]$$

3.1.3. Production of land transport (OTP)

As Figure 2.3 shows, the driving-related component is included in the OTP. The rest of the production structure is the same except that transport-capital and refined oil consumption are included in the driving -related component. Figure 2.4 shows the nesting structure of the driving-related component.

3.1.3.1. Driving-related component of land transport (OTP)

We combine services of new and old cars following the constant elasticity of substitution (CES) function, where P_{NCAR}^{OTP} and P_{OCAR}^{OTP} are the prices of the composite of the services of new and old cars in OTP, and P_{DRI} is the price of the composite of the services of new and old cars in OTP:

$$\frac{P_{DRI}}{\overline{P}_{DRI}}=\left[\theta_{OTP}^{NCAR}\left(\frac{P_{NCAR}^{OTP}}{\overline{P}_{NCAR}^{OTP}}\right)^{1-\sigma^{on}}+\theta_{OTP}^{OCAR}\left(\frac{P_{OCAR}^{OTP}}{\overline{P}_{OCAR}^{OTP}}\right)^{1-\sigma^{on}}\right]^{\frac{1}{1-\sigma^{on}}}$$

The composite of services of new cars consists of services of new EVs and new ICEs, and EVs and ICEs are substitutable. θ_{OTP}^{NEV} and θ_{OTP}^{NICE} represents the value share of new EVs and new ICE in OTP:

$$\frac{P_{NCAR}^{OTP}}{\overline{P}_{NCAR}^{OTP}}=\left[\theta_{OTP}^{NEV}\left(\frac{P_{NEV}^{OTP}}{\overline{P}_{NEV}^{OTP}}\right)^{1-\sigma^{trpr}}+\theta_{OTP}^{NICE}\left(\frac{P_{NICE}^{OTP}}{\overline{P}_{NICE}^{OTP}}\right)^{1-\sigma^{trpr}}\right]^{\frac{1}{1-\sigma^{trpr}}}$$

[6] The model user can define which industries are included in the set xe. In the standard version, $xe \in \{CRU, COA, GAS\}$, but also other industries (AGR, ELE) have been included in different model versions.

[7] This assumption used to be the default assumption as a conservative view on the substitution possibilities. However, we currently relax them for CRU and ELE, and they follow the CES function. Depending on the analysis, we can choose different settings.

$$\frac{P_{OCAR}^{OTP}}{\bar{P}_{OCAR}^{OTP}} = \left[\theta_{OTP}^{OEV}\left(\frac{P_{OEV}^{OTP}}{\bar{P}_{OEV}^{OTP}}\right)^{1-\sigma^{trpr}} + \theta_{OTP}^{OICE}\left(\frac{P_{OICE}^{OTP}}{\bar{P}_{OICE}^{OTP}}\right)^{1-\sigma^{trpr}}\right]^{\frac{1}{1-\sigma^{trpr}}}$$

The price of services of EVs consists of the rental value of old and new EVs (P_{ROEV}^{OTP} and P_{RNEV}^{OTP}), electricity consumption (P_{ELE}). OEEV is the consumption of electricity related to EVs in OTP:

$$\frac{P_{OEV}^{OTP}}{\bar{P}_{OEV}^{OTP}} = \left[\theta_{old}^{oeev}\left(\frac{P_{ELE}}{\bar{P}_{ELE}}\right)^{1-\sigma^{oeev}} + (1-\theta_{old}^{oeev})\left(\frac{P_{ROEV}^{OTP}}{\bar{P}_{ROEV}^{OTP}}\right)^{1-\sigma^{oeev}}\right]^{\frac{1}{1-\sigma^{oeev}}}$$

$$\frac{P_{NEV}^{OTP}}{\bar{P}_{NEV}^{OTP}} = \left[\theta_{new}^{oeev}\left(\frac{P_{ELE}}{\bar{P}_{ELE}}\right)^{1-\sigma^{oeev}} + (1-\theta_{new}^{oeev})\left(\frac{P_{RNEV}^{OTP}}{\bar{P}_{RNEV}^{OTP}}\right)^{1-\sigma^{oeev}}\right]^{\frac{1}{1-\sigma^{oeev}}}$$

Similarly, the price of services of ICEs consists of the rental value of old and new ICE (P_{ROICE}^{OTP} and P_{RNICE}^{OTP}), and petrol/diesel (including biofuels) consumption (P_{OIL}).

$$\frac{P_{OICE}^{OTP}}{\bar{P}_{OICE}^{OTP}} = \left[\theta_{new}^{oil}\left(\frac{P_{OIL}}{\bar{P}_{\mathrm{OIL}}}\right)^{1-\sigma^{oil}} + (1-\theta_{new}^{oil})\left(\frac{P_{ROICE}^{OTP}}{\bar{P}_{ROICE}^{OTP}}\right)^{1-\sigma^{oil}}\right]^{\frac{1}{1-\sigma^{oil}}}$$

$$\frac{P_{NICE}^{OTP}}{\bar{P}_{NICE}^{OTP}} = \left[\theta_{new}^{oil}\left(\frac{P_{OIL}}{\bar{P}_{\mathrm{OIL}}}\right)^{1-\sigma^{oil}} + (1-\theta_{new}^{oil})\left(\frac{P_{RNICE}^{OTP}}{\bar{P}_{RNICE}^{OTP}}\right)^{1-\sigma^{oil}}\right]^{\frac{1}{1-\sigma^{oil}}}$$

3.1.4. Production of goods for final consumption

Consumption goods *c* are produced using output of production sectors with a CES production function (similar to the one in production, except that they do not have input of capital and labour and substitution elasticities typically equal to zero).

3.1.4.1. E vs. M

Material aggregate (intermediate input from other industries except energy goods) trades off with the energy aggregate:

$$\frac{P_{P,c}}{\bar{P}_{P,c}} = \left[\theta_c^E\left(\frac{P_{E,c}}{\bar{P}_{E,c}}\right)^{1-\sigma_c^Y} + \theta_c^{MAT}\left(\frac{P_{MAT,c}}{\bar{P}_{MAT,c}}\right)^{1-\sigma_c^Y}\right]^{\frac{1}{1-\sigma_c^Y}}$$

3.1.4.2. Intermediate inputs (M sub-nest)

Intermediate inputs (Armington goods) from industries *ii* (except energy goods ELE, OIL, GAS, COA), are combined in production of the consumption good:

$$\frac{P_{MAT,c}}{\bar{P}_{MAT,c}} = \left[\sum_{ii\in NEN}\theta_{c,ii}^A\left(\frac{P_{A,ii}(1+t_{A,c,ii})}{\bar{P}_{A,ii}(1+\bar{t}_{A,c,ii})}\right)^{1-\sigma_c^{MAT}}\right]^{\frac{1}{1-\sigma_c^{MAT}}}$$

Input taxes ($t_{A,i,ii}$) may be applied for use of good *ii*.

3.1.4.3. The energy sub-nest

Energy goods are combined in a nested CES function in the same way as in production:

Electricity (ELE) vs. non-electricity (NELE = oil, gas, coal)

$$\frac{P_{E,c}}{\overline{P}_{E,c}} = \left[\theta_c^{ELE}\left(\frac{P_{A,ELE}\left(1+t_{A,c,ELE}\right)}{\overline{P}_{A,ELE}\left(1+\overline{t}_{A,c,ELE}\right)}\right)^{1-\sigma_c^E} + \theta_c^{NELE}\left(\frac{P_{NELE,c}}{\overline{P}_{NELE,c}}\right)^{1-\sigma_c^E}\right]^{\frac{1}{1-\sigma_c^E}}$$

Oil and gas (LQD) vs. coal (COA)

$$\frac{P_{NELE,c}}{\overline{P}_{NELE,c}} = \left[\theta_c^{LQD}\left(\frac{P_{LQD,c}}{\overline{P}_{LQD,c}}\right)^{1-\sigma_c^{NELE}} + \theta_c^{COA}\left(\frac{P_{A,COA}\left(1+t_{A,c,COA}\right)}{\overline{P}_{A,COA}\left(1+\overline{t}_{A,c,COA}\right)}\right)^{1-\sigma_c^{NELE}}\right]^{\frac{1}{1-\sigma_c^{NELE}}}$$

Oil (OIL) vs. gas (GAS)

$$\frac{P_{LQD,c}}{\overline{P}_{LQD,c}} = \left[\theta_c^{OIL}\left(\frac{P_{A,OIL}\left(1+t_{A,c,OIL}\right)}{\overline{P}_{A,OIL}\left(1+\overline{t}_{A,c,OIL}\right)}\right)^{1-\sigma_c^{LQD}} + \theta_c^{GAS}\left(\frac{P_{A,GAS}\left(1+t_{A,c,GAS}\right)}{\overline{P}_{A,GAS}\left(1+\overline{t}_{A,c,GAS}\right)}\right)^{1-\sigma_c^{LQD}}\right]^{\frac{1}{1-\sigma_c^{LQD}}}$$

3.1.5. Exports vs. domestic supply (CET-function)

Output of sector *i* can be sold at the domestic market or exported. This is modelled through a CET-function:

$$\frac{P_{Y,i}}{\overline{P}_{Y,i}} = \left[\theta_i^{DY}\left(\frac{P_{DOM,i}}{\overline{P}_{DOM,i}}\right)^{1+\eta_i^T} + \theta_i^X\left(\frac{P_{X,i}}{\overline{P}_{X,i}}\right)^{1+\eta_i^T}\right]^{\frac{1}{1+\eta_i^T}}$$

3.1.6. Household utility

Utility of the representative consumer is defined by a CES function that combines full consumption and investment (savings) demand. Savings is determined by a marginal propensity to save.

$$\frac{P_U}{\overline{P}_U} = \left[\theta^{FC}\left(\frac{P_{FC}}{\overline{P}_{FC}}\right)^{1-\sigma^U} + \theta^S\left(\frac{P_S}{\overline{P}_S}\right)^{1-\sigma^U}\right]^{\frac{1}{1-\sigma^U}}$$

The price of savings consists of the following components:

$$\frac{P_S}{\overline{P}_S} = \frac{P_C}{\overline{P}_C}\frac{P_I}{\overline{P}_I}\frac{\overline{P}_{KS}}{P_{KS}}$$

Full consumption is defined as a CES composite of material consumption and leisure. The corresponding price index is given by:

$$\frac{P_{FC}}{\overline{P}_{FC}} = \left[\theta_C\left(\frac{P_C}{\overline{P}_C}\right)^{1-\sigma^{CL}} + (1-\theta^C)\left(\frac{P_{LE}}{\overline{P}_{LE}}\right)^{1-\sigma^{CL}}\right]^{\frac{1}{1-\sigma^{CL}}}$$

3.1.7. Consumption function for material consumption

At the top level, consumption of housing services, transport services and all other goods and services are combined in a CES-function, see Figure 2.5:

$$\frac{P_C}{\overline{P}_C} = \left[\theta_c^{TR}\left(\frac{P_{TR}}{\overline{P}_{TR}}\right)^{1-\sigma^C} + \theta_c^{HOU}\left(\frac{P_{HOU}}{\overline{P}_{HOU}}\right)^{1-\sigma^C} + \theta_c^{other}\left(\frac{P_{other}}{\overline{P}_{other}}\right)^{1-\sigma^C}\right]^{\frac{1}{1-\sigma^C}}$$

3.1.8. Other goods and services aggregate

$$\frac{P_{other}}{\overline{P}_{other}} = \left[\sum_{c\in other} \theta_c^{other} \left(\frac{P_{P,c}(1+t_{VAT,c})}{\overline{P}_{P,c}(1+\bar{t}_{VAT,c})}\right)^{1-\sigma_c^{other}}\right]^{\frac{1}{1-\sigma_c^{other}}}$$

3.1.9. Transport aggregate

$$\frac{P_{TR}}{\overline{P}_{TR}} = \left[\theta^{CTRP}\left(\frac{P_{CTRP}}{\overline{P}_{CTRP}}\right)^{1-\sigma^{TRNT}} + \theta^{CTRN}\left(\frac{P_{CTRN}}{\overline{P}_{CTRN}}\right)^{1-\sigma^{TRNT}}\right]^{\frac{1}{1-\sigma^{TRNT}}}$$

3.1.9.1. Private transport

New vs. old car

At the top nest of private transport, we combine services of new and old cars following the constant elasticity of substitution (CES) function, where P_{NCAR} and P_{OCAR} are the prices of the composite of the services of new and old cars:

$$\frac{P_{CTRN}}{\overline{P}_{CTRN}} = \left[\theta^{NCAR}\left(\frac{P_{NCAR}}{\overline{P}_{NCAR}}\right)^{1-\sigma^{on}} + \theta^{OCAR}\left(\frac{P_{OCAR}}{\overline{P}_{OCAR}}\right)^{1-\sigma^{on}}\right]^{\frac{1}{1-\sigma^{on}}}$$

Service of new and old cars

The composite of services of new cars consists of services of new EVs (electric vehicles) and new ICEs (internal combustion engine vehicles), and EVs and ICEs are substitutable. In other words, when the households buy a new car, they can decide which type of car they buy with relative prices including the subsidy on EV (S_{EV}) and tax on ICE (t_{ICE}). θ^{NEV} and θ^{NICE} represents the value share of new EVs and new ICE:

$$\frac{P_{NCAR}}{\overline{P}_{NCAR}} = \left[\theta^{NEV}\left(\frac{P_{NEV}(1-s_{EV})}{\overline{P}_{NEV}(1-\bar{s}_{EV})}\right)^{1-\sigma^{trpr}} + \theta^{NICE}\left(\frac{P_{NICE}(1+t_{ICE})}{\overline{P}_{NICE}(1+\bar{t}_{ICE})}\right)^{1-\sigma^{trpr}}\right]^{\frac{1}{1-\sigma^{trpr}}}$$

$$\frac{P_{OCAR}}{\overline{P}_{OCAR}} = \left[\theta^{OEV}\left(\frac{P_{OEV}(1-s_{EV})}{\overline{P}_{OEV}(1-\bar{s}_{EV})}\right)^{1-\sigma^{trpr}} + \theta^{OICE}\left(\frac{P_{OICE}(1+t_{ICE})}{\overline{P}_{OICE}(1+\bar{t}_{ICE})}\right)^{1-\sigma^{trpr}}\right]^{\frac{1}{1-\sigma^{trpr}}}$$

Service of EVs

The price of services of EVs consists of the rental value of old and new EVs (P_{ROEV} *and* P_{RNEV}), electricity consumption (P_{ELE}) and other costs ($P_{i,EV}$) (where the set i represents the good or service). CEEV is the consumption of electricity related to EVs:

$$\frac{P_{NEV}}{\overline{P}_{NEV}} = \left[\theta_{new}^{ceev}\left(\frac{P_{ELE}}{\overline{P}_{ELE}}\right)^{1-\sigma^{ceev}} + (1-\theta_{new}^{ceev})\left(\theta_{new}^{EV}\left(\frac{P_{RNEV}(1+t_{C,RNEV})}{\overline{P}_{RNEV}(1+\bar{t}_{C,RNEV})}\right) + \sum_i \theta_{i,new}^{EV}\left(\frac{P_{i,EV}}{\overline{P}_{i,EV}}\right)\right)^{1-\sigma^{ceev}}\right]^{\frac{1}{1-\sigma^{ceev}}}$$

$$\frac{P_{OEV}}{\overline{P}_{OEV}} = \left[\theta_{old}^{ceev}\left(\frac{P_{ELE}}{\overline{P}_{ELE}}\right)^{1-\sigma^{ceev}} + (1-\theta_{old}^{ceev})\left(\theta_{old}^{EV}\left(\frac{P_{ROEV}(1+t_{C,ROEV})}{\overline{P}_{ROEV}(1+\bar{t}_{C,ROEV})}\right) + \sum_i \theta_{i,old}^{EV}\left(\frac{P_{i,EV}}{\overline{P}_{i,EV}}\right)\right)^{1-\sigma^{ceev}}\right]^{\frac{1}{1-\sigma^{ceev}}}$$

Similarly, the price of services of ICEs consists of the rental value of old and new ICE (P_{ROICE} *and* P_{RNICE}), petrol/diesel consumption (P_{CPAD}), and other costs ($P_{i,ICE}$).

$$\frac{P_{NICE}}{\bar{P}_{NICE}} = \left[\theta_{new}^{cpad}\left(\frac{P_{CPAD}}{\bar{P}_{\mathrm{CPAD}}}\right)^{1-\sigma^{cpad}} + \left(1-\theta_{new}^{cpad}\right)\left(\theta_{new}^{ICE}\left(\frac{P_{RNICE}(1+t_{C,RNICE})}{\bar{P}_{RNICE}(1+\bar{t}_{C,RNICE})}\right) + \sum_i \theta_{i,new}^{ICE}\left(\frac{P_{i,ICE}}{\bar{P}_{i,ICE}}\right)\right)^{1-\sigma^{cpad}}\right]^{\frac{1}{1-\sigma^{cpad}}}$$

$$\frac{P_{OICE}}{\bar{P}_{OICE}} = \left[\theta_{old}^{cpad}\left(\frac{P_{CPAD}}{\bar{P}_{\mathrm{CPAD}}}\right)^{1-\sigma^{cpad}} + \left(1-\theta_{old}^{cpad}\right)\left(\theta_{old}^{ICE}\left(\frac{P_{ROICE}(1+t_{C,ROICE})}{\bar{P}_{ROICE}(1+\bar{t}_{C,ROICE})}\right) + \sum_i \theta_{i,old}^{ICE}\left(\frac{P_{i,ICE}}{\bar{P}_{i,ICE}}\right)\right)^{1-\sigma^{cpad}}\right]^{\frac{1}{1-\sigma^{cpad}}}$$

Note that while we do not include VAT in the equations above (to reduce the complexity of the equations), they are included for consumption of all the consumption commodities.

3.1.9.2. Public transport

$$\frac{P_{CTRP}}{\bar{P}_{CTRP}} = \left[\begin{array}{l} \theta^{CRAI}\left(\frac{P_{P,CRAI}\left(1+t_{VAT,CRAI}\right)}{\bar{P}_{P,CRAI}\left(1+\bar{t}_{VAT,CRAI}\right)}\right)^{1-\sigma^{CTRP}} + \theta^{CROA}\left(\frac{P_{P,CROA}\left(1+t_{VAT,CROA}\right)}{\bar{P}_{P,CROA}\left(1+\bar{t}_{VAT,CROA}\right)}\right)^{1-\sigma^{CTRP}} \\ +\theta^{CAIR}\left(\frac{P_{P,CAIR}\left(1+t_{VAT,CAIR}\right)}{\bar{P}_{P,CAIR}\left(1+\bar{t}_{VAT,CAIR}\right)}\right)^{1-\sigma^{CTRP}} + \theta^{CBOA}\left(\frac{P_{P,CBOA}\left(1+t_{VAT,CBOA}\right)}{\bar{P}_{P,CBOA}\left(1+\bar{t}_{VAT,CBOA}\right)}\right)^{1-\sigma^{CTRP}} \end{array}\right]^{\frac{1}{1-\sigma^{CTRP}}}$$

3.1.9.3. Housing aggregate

Dwellings vs. Energy

$$\frac{P_{HOU}}{\bar{P}_{HOU}} = \left[\theta^{DWE}\left(\frac{P_{P,CHAW}\left(1+t_{VAT,CHAW}\right)}{\bar{P}_{P,CHAW}\left(1+\bar{t}_{VAT,CHAW}\right)}\right)^{1-\sigma^{HOU}} + \theta^{ENE}\left(\frac{P_{ENE}}{\bar{P}_{ENE}}\right)^{1-\sigma^{HOU}}\right]^{\frac{1}{1-\sigma^{HOU}}}$$

Energy aggregate in housing

$$\frac{P_{ENE}}{\bar{P}_{ENE}} = \left[\theta^{ELE}\left(\frac{P_{P,CELE}\left(1+t_{VAT,CELE}\right)}{\bar{P}_{P,CELE}\left(1+\bar{t}_{VAT,CELE}\right)}\right)^{1-\sigma^{ENE}} + \theta^{NELE}\left(\frac{P_{NELE}}{\bar{P}_{NELE}}\right)^{1-\sigma^{ENE}}\right]^{\frac{1}{1-\sigma^{ENE}}}$$

Non-electricity aggregate

$$\frac{P_{NELE}}{\bar{P}_{NELE}} = \left[\begin{array}{l} \theta^{CGAS}\left(\frac{P_{P,CGAS}\left(1+t_{VAT,CGAS}\right)}{\bar{P}_{P,CGAS}\left(1+\bar{t}_{VAT,CGAS}\right)}\right)^{1-\sigma^{NELE}} + \theta^{CPAH}\left(\frac{P_{P,CPAH}\left(1+t_{VAT,CPAH}\right)}{\bar{P}_{P,CPAH}\left(1+\bar{t}_{VAT,CPAH}\right)}\right)^{1-\sigma^{NELE}} \\ +\theta^{CFAC}\left(\frac{P_{P,CFAC}\left(1+t_{VAT,CFAC}\right)}{\bar{P}_{P,CFAC}\left(1+\bar{t}_{VAT,CFAC}\right)}\right)^{1-\sigma^{NELE}} + \theta^{CDHE}\left(\frac{P_{P,CDHE}\left(1+t_{VAT,CDHE}\right)}{\bar{P}_{P,CDHE}\left(1+\bar{t}_{VAT,CDHE}\right)}\right)^{1-\sigma^{NELE}} \end{array}\right]^{\frac{1}{1-\sigma^{NELE}}}$$

3.1.10. Government demand

Government demand consists of government investments and inputs from the production sectors:

$$\frac{P_G}{\bar{P}_G} = \theta_G^I \frac{P_{IG}}{\bar{P}_{IG}} + \sum_i \theta_G^i \left(\frac{P_{A,i}}{\bar{P}_{A,i}}\right)$$

3.1.11. Investment good
Investment good is also produced with fixed coefficients

$$\frac{P_I}{\overline{P}_I} = \sum_i \theta_I^i \left(\frac{P_{A,i}}{\overline{P}_{A,i}}\right)$$

3.1.12. Government investment good
Government investment good is also produced with fixed coefficients

$$\frac{P_{IG}}{\overline{P}_{IG}} = \sum_i \theta_{IG}^i \left(\frac{P_{A,i}}{\overline{P}_{A,i}}\right)$$

3.1.13. Capital supply
If domestic and foreign capital are imperfect substitutes, capital supply is transformed into domestic use and capital exports through a CET-function.

$$\frac{P_{KS}}{\overline{P}_{KS}} = \left[\theta^{KD}\left(\frac{P_{KD}}{\overline{P}_{KD}}\right)^{1+\eta^K} + \theta_i^{KX}\left(\frac{P_{KX}}{\overline{P}_{KX}}\right)^{1+\eta^K}\right]^{\frac{1}{1+\eta^K}}$$

3.1.14. Capital in the domestic market (Armington)
Domestic and imported capital are imperfect substitutes in production:

$$\frac{P_{KA}}{\overline{P}_{KA}} = \left[\theta^{KD}\left(\frac{P_{KD}}{\overline{P}_{KD}}\right)^{1-\sigma^K} + \theta_i^{KM}\left(\frac{P_{KM}}{\overline{P}_{KM}}\right)^{1-\sigma^K}\right]^{\frac{1}{1-\sigma^K}}$$

3.1.15. Allocation of new capital on different capital types
The new capital is allocated on the three types of capital, depending on capital earnings (alternatively, this could be replaced by a CET-function) where P_{KV}^{AT} is after tax:

$$\frac{P_{KV}^{AT}}{\overline{P}_{KV}^{AT}} = \frac{P_{KA}}{\overline{P}_{KA}} \ for\ KV \in \{KMA, KBA, KTR\}$$

3.1.16. Income taxation
Income tax is applied to both labour and capital.

$$\frac{P_{KV}(1-t_I)}{\overline{P}_{KV}(1-\bar{t}_I)} = \frac{P_{KV}^{AT}}{\overline{P}_{KV}^{AT}} \ for\ KV \in \{KMA, KBA, KTR\}$$

$$\frac{P_L(1-t_I)}{\overline{P}_L(1-\bar{t}_I)} = \frac{P_{LE}}{\overline{P}_{LE}}$$

3.2. Demand and supply equations

3.2.1. Demand for input factors and intermediate products
For the sectors with the resource factor, Y_i should be the composite of all the inputs except the resource factor.

$$\frac{MAT_i}{\overline{MAT}_i} = \frac{Y_i}{\overline{Y}_i}\left(\frac{P_{Y,i}(1-t_{Y,i})\overline{P}_{MAT,i}}{\overline{P}_{Y,i}(1-\overline{t}_{Y,i})P_{MAT,i}}\right)^{\sigma_i^Y}$$

$$\frac{A_{ii,i}}{\overline{A}_{ii,i}} = \frac{MAT_i}{\overline{MAT}_i}\left(\frac{P_{MAT,i}(1+\overline{t}_{A,i,ii})\overline{P}_{A,ii}}{\overline{P}_{MAT,i}(1+t_{A,i,ii})P_{A,ii}}\right)^{\sigma_i^{MAT}}$$

(for $ii \in NEN$)

$$\frac{KLE_i}{\overline{KLE}_i} = \frac{Y_i}{\overline{Y}_i}\left(\frac{P_{Y,i}(1-t_{Y,i})\overline{P}_{KLE,i}}{\overline{P}_{Y,i}(1-\overline{t}_{Y,i})P_{KLE,i}}\right)^{\sigma_i^Y}$$

$$\frac{KL_i}{\overline{KL}_i} = \frac{KLE_i}{\overline{KLE}_i}\left(\frac{P_{KLE,i}\overline{P}_{KL,i}}{\overline{P}_{KLE,i}P_{KL,i}}\right)^{\sigma_i^{KLE}}$$

$$\frac{K_i}{\overline{K}_i} = \frac{KL_i}{\overline{KL}_i}\left(\frac{P_{KL,i}\overline{P}_{K,i}}{\overline{P}_{KL,i}P_{K,i}}\right)^{\sigma_i^{KL}}$$

$$\frac{KV_i}{\overline{KV}_i} = \frac{K_i}{\overline{K}_i}\left(\frac{P_{K,i}\overline{P}_{KV}}{\overline{P}_{K,i}P_{KV}}\right)^{\sigma_i^{K}}$$

$$\frac{L_i}{\overline{L}_i} = \frac{KL_i}{\overline{KL}_i}\left(\frac{P_{KL,i}(1+\overline{t}_{L,i})\overline{P}_L}{\overline{P}_{KL,i}(1+t_{L,i})P_L}\right)^{\sigma_i^{KL}}$$

$$\frac{E_i}{\overline{E}_i} = \frac{KLE_i}{\overline{KLE}_i}\left(\frac{P_{KLE,i}\overline{P}_{E,i}}{\overline{P}_{KLE,i}P_{E,i}}\right)^{\sigma_i^{KLE}}$$

$$\frac{NELE_i}{\overline{NELE}_i} = \frac{E_i}{\overline{E}_i}\left(\frac{P_{E,i}\overline{P}_{NELE,i}}{\overline{P}_{E,i}P_{NELE,i}}\right)^{\sigma_i^{E}}$$

$$\frac{A_{ELE,i}}{\overline{A}_{ELE,i}} = \frac{E_i}{\overline{E}_i}\left(\frac{P_{E,i}(1+\overline{t}_{A,i,ELE})\overline{P}_{A,ELE}}{\overline{P}_{E,i}(1+t_{A,i,ELE})P_{A,ELE}}\right)^{\sigma_i^{E}}$$

$$\frac{A_{COA,i}}{\overline{A}_{COA,i}} = \frac{NELE_i}{\overline{NELE}_i}\left(\frac{P_{NELE,i}(1+\overline{t}_{A,i,COA})\overline{P}_{A,COA}}{\overline{P}_{NELE,i}(1+t_{A,i,COA})P_{A,COA}}\right)^{\sigma_i^{NELE}}$$

$$\frac{LQD_i}{\overline{LQD}_i} = \frac{NELE_i}{\overline{NELE}_i}\left(\frac{P_{NELE,i}\overline{P}_{LQD,i}}{\overline{P}_{NELE,i}P_{LQD,i}}\right)^{\sigma_i^{NELE}}$$

$$\frac{A_{j,i}}{\overline{A}_{j,i}} = \frac{LQD_i}{\overline{LQD}_i}\left(\frac{P_{LQD,i}(1+\overline{t}_{A,i,j})\overline{P}_{A,j}}{\overline{P}_{LQD,i}(1+t_{A,i,j})P_{A,j}}\right)^{\sigma_i^{LQD}}$$

for $j \in \{OIL, GAS\}$

3.2.2. Demand for the resource factor in the sectors with the resource factor

$$\frac{R_i}{\overline{R}_i} = \frac{Y_i}{\overline{Y}_i}\left(\frac{P_{Y,i}(1-t_{Y,i})\overline{P}_{R,i}}{\overline{P}_{Y,i}(1-\overline{t}_{Y,i})P_{R,i}}\right)^{\sigma_i^Y}$$

3.2.3. Demand for the inputs in driving-related component in OTP

$$\frac{NCAR^{OTP}}{\overline{NCAR}^{OTP}} = \frac{DRI}{\overline{DRI}}\left(\frac{P_{DRI}\overline{P}_{NCAR}^{OTP}}{\overline{P}_{DRI}P_{NCAR}^{OTP}}\right)^{\sigma^{on}}$$

$$\frac{OCAR^{OTP}}{\overline{OCAR}^{OTP}} = \frac{DRI}{\overline{DRI}}\left(\frac{P_{DRI}\overline{P}_{OCAR}^{OTP}}{\overline{P}_{DRI}P_{OCAR}^{OTP}}\right)^{\sigma^{on}}$$

$$\frac{NEV^{OTP}}{\overline{NEV}^{OTP}} = \frac{NCAR^{OTP}}{\overline{NCAR}^{OTP}}\left(\frac{P_{NCAR}^{OTP}\overline{P}_{NEV}^{OTP}}{\overline{P}_{NCAR}^{OTP}P_{NEV}^{OTP}}\right)^{\sigma^{trpr}}$$

$$\frac{NICE^{OTP}}{\overline{NICE}^{OTP}} = \frac{NCAR^{OTP}}{\overline{NCAR}^{OTP}}\left(\frac{P_{NCAR}^{OTP}\overline{P}_{NICE}^{OTP}}{\overline{P}_{NCAR}^{OTP}P_{NICE}^{OTP}}\right)^{\sigma^{trpr}}$$

$$\frac{OEV^{OTP}}{\overline{OEV}^{OTP}} = \frac{OCAR^{OTP}}{\overline{OCAR}^{OTP}}\left(\frac{P_{OCAR}^{OTP}\overline{P}_{OEV}^{OTP}}{\overline{P}_{OCAR}^{OTP}P_{OEV}^{OTP}}\right)^{\sigma^{trpr}}$$

$$\frac{OICE^{OTP}}{\overline{OICE}^{OTP}} = \frac{OCAR^{OTP}}{\overline{OCAR}^{OTP}}\left(\frac{P_{OCAR}^{OTP}\overline{P}_{OICE}^{OTP}}{\overline{P}_{OCAR}^{OTP}P_{OICE}^{OTP}}\right)^{\sigma^{trpr}}$$

$$OEEV = \overline{A_{ELE,OEV}^{OTP}}\frac{OEV^{OTP}}{\overline{OEV}^{OTP}}\left(\frac{P_{OEV}^{OTP}\overline{P}_{ELE}}{\overline{P}_{OEV}^{OTP}P_{ELE}}\right)^{\sigma^{oeev}} + \overline{A_{ELE,NEV}^{OTP}}\frac{NEV^{OTP}}{\overline{NEV}^{OTP}}\left(\frac{P_{NEV}^{OTP}\overline{P}_{ELE}}{\overline{P}_{NEV}^{OTP}P_{ELE}}\right)^{\sigma^{oeev}}$$

$$A_{OIL,OTP} = \overline{A_{OIL,OICE}^{OTP}}\frac{OICE^{OTP}}{\overline{OICE}^{OTP}}\left(\frac{P_{OICE}^{OTP}\overline{P}_{OIL}}{\overline{P}_{OICE}^{OTP}P_{OIL}}\right)^{\sigma^{oil}} + \overline{A_{OIL,NICE}^{OTP}}\frac{NICE}{\overline{NICE}}\left(\frac{P_{NICE}^{OTP}\overline{P}_{CPAD}}{\overline{P}_{NICE}^{OTP}P_{CPAD}}\right)^{\sigma^{oil}}$$

$$\frac{ORICE_{OTP}}{\overline{ORICE}_{OTP}} = \frac{OICE^{OTP}}{\overline{OICE}^{OTP}}\left(\frac{P_{OICE}^{OTP}\overline{P}_{ORICE}^{OTP}}{\overline{P}_{OICE}^{OTP}P_{ORICE}^{OTP}}\right)^{\sigma^{oil}}$$

$$\frac{NRICE_{OTP}}{\overline{NRICE}_{OTP}} = \frac{NICE^{OTP}}{\overline{NICE}^{OTP}}\left(\frac{P_{NICE}^{OTP}\overline{P}_{NRICE}^{OTP}}{\overline{P}_{NICE}^{OTP}P_{NRICE}^{OTP}}\right)^{\sigma^{oil}}$$

$$\frac{OREV_{OTP}}{\overline{OREV}_{OTP}} = \frac{OEV^{OTP}}{\overline{OEV}^{OTP}}\left(\frac{P_{OEV}^{OTP}\overline{P}_{OREV}^{OTP}}{\overline{P}_{OEV}^{OTP}P_{OREV}^{OTP}}\right)^{\sigma^{oeev}}$$

$$\frac{NREV_{OTP}}{\overline{NREV}_{OTP}} = \frac{NEV^{OTP}}{\overline{NEV}^{OTP}}\left(\frac{P_{NEV}^{OTP}\overline{P}_{NREV}^{OTP}}{\overline{P}_{NEV}^{OTP}P_{NREV}^{OTP}}\right)^{\sigma^{oeev}}$$

The supply of old cars consists of the old cars in the previous period and new cars in the previous period (considering that some old cars are scrapped).

$$ORICE_{OTP} = (1-\delta)(ORICE_{OTP,-1} + NRICE_{OTP,-1})$$

$$OEV_{OTP} = (1-\delta)(OEV_{OTP,-1} + NEV_{OTP,-1})$$

The supply of new cars (SCAR) is equal to the demand.

$$SCAR_{ICE} = NRICE_{OTP}$$

$$SCAR_{EV} = NREV_{OTP}$$

The supply of new cars is adjusted such that the percentage change of the imported car prices is equal to the percentage change of the price of the rental value of the new cars:

$$\frac{PM_{ICE}^{OTP}}{\overline{PM}_{ICE}^{OTP}} = \frac{P_{NRICE}^{OTP}}{\overline{P}_{NRICE}^{OTP}}$$

$$\frac{PM_{EV}^{OTP}}{\overline{PM}_{EV}^{OTP}} = \frac{P_{NREV}^{OTP}}{\overline{P}_{NREV}^{OTP}}$$

3.2.4. Demand for intermediate products in production of consumption goods

$$\frac{MAT_c}{\overline{MAT}_c} = \frac{Y_c}{\overline{Y}_c}\left(\frac{P_{P,c}(1-t_{Y,i})\overline{P}_{MAT,c}}{\overline{P}_{P,c}(1-\overline{t}_{Y,i})P_{MAT,c}}\right)^{\sigma_c^Y}$$

(for $ii \in NEN$)

$$\frac{A_{ii,c}}{\overline{A}_{ii,c}} = \frac{MAT_c}{\overline{MAT}_c}\left(\frac{P_{MAT,c}(1+\overline{t}_{A,c,ii})\overline{P}_{A,c}}{\overline{P}_{MAT,c}(1+t_{A,c,ii})P_{A,c}}\right)^{\sigma_i^{MAT}}$$

(for $ii \in NEN$)

$$\frac{E_c}{\overline{E}_c} = \frac{Y_c}{\overline{Y}_c}\left(\frac{P_{P,c}(1-t_{Y,i})\overline{P}_{E,c}}{\overline{P}_{P,c}(1-\overline{t}_{Y,i})P_{E,c}}\right)^{\sigma_c^Y}$$

$$\frac{NELE_c}{\overline{NELE}_c} = \frac{E_c}{\overline{E}_c}\left(\frac{P_{E,c}\overline{P}_{NELE,c}}{\overline{P}_{E,c}P_{NELE,c}}\right)^{\sigma_c^E}$$

$$\frac{A_{ELE,c}}{\overline{A}_{ELE,c}} = \frac{E_c}{\overline{E}_c}\left(\frac{P_{E,c}(1+\overline{t}_{A,c,ELE})\overline{P}_{A,ELE}}{\overline{P}_{E,c}(1+t_{A,c,ELE})P_{A,ELE}}\right)^{\sigma_c^E}$$

$$\frac{A_{COA,c}}{\overline{A}_{COA,c}} = \frac{NELE_c}{\overline{NELE}_c}\left(\frac{P_{NELE,c}(1+\overline{t}_{A,c,COA})\overline{P}_{A,COA}}{\overline{P}_{NELE,c}(1+t_{A,c,COA})P_{A,COA}}\right)^{\sigma_c^{NELE}}$$

$$\frac{LQD_c}{\overline{LQD}_c} = \frac{NELE_c}{\overline{NELE}_c}\left(\frac{P_{NELE,c}\overline{P}_{LQD,c}}{\overline{P}_{NELE,c}P_{LQD,c}}\right)^{\sigma_c^{NELE}}$$

$$\frac{A_{j,c}}{\overline{A}_{j,c}} = \frac{LQD_c}{\overline{LQD}_c}\left(\frac{P_{LQD,c}(1+\overline{t}_{A,c,j})\overline{P}_{A,j}}{\overline{P}_{LQD,c}(1+t_{A,c,j})P_{A,j}}\right)^{\sigma_c^{LQD}}$$

for $j \in \{OIL, GAS\}$

3.2.5. Armington demands for imports (M) and domestic goods (D):

$$\frac{D_i}{\overline{D}_i} = \frac{A_i}{\overline{A}_i}\left(\frac{P_{A,i}\overline{P}_{D,i}}{\overline{P}_{A,i}P_{D,i}}\right)^{\sigma_i^A}$$

$$\frac{M_i}{\overline{M}_i} = \frac{A_i}{\overline{A}_i}\left(\frac{P_{A,i}\overline{P}_{M,i}(1+\bar{t}_{M,i})}{\overline{P}_{A,i}P_{M,i}(1+t_{Mi})}\right)^{\sigma_i^A}$$

3.2.6. Supply to the domestic and export markets:

$$\frac{D_i}{\overline{D}_i} = \frac{Y_i}{\overline{Y}_i}\left(\frac{\overline{P}_{Y,i}P_{D,i}}{P_{Y,i}\overline{P}_{D,i}}\right)^{\eta_i^T}$$

$$\frac{X_i}{\overline{X}_i} = \frac{Y_i}{\overline{Y}_i}\left(\frac{\overline{P}_{Y,i}P_{X,i}}{P_{Y,i}\overline{P}_{X,i}}\right)^{\eta_i^T}$$

3.2.7. Demand for goods in the household demand function

$$\frac{S}{\overline{S}} = \frac{U}{\overline{U}}\left(\frac{P_U\overline{P}_S}{\overline{P}_U P_S}\right)^{\sigma^U}$$

$$\frac{FC}{\overline{FC}} = \frac{U}{\overline{U}}\left(\frac{P_U\overline{P}_{FC}}{\overline{P}_U P_{FC}}\right)^{\sigma^U}$$

$$\frac{C}{\overline{C}} = \frac{FC}{\overline{FC}}\left(\frac{P_{FC}\overline{P}_C}{\overline{P}_{FC} P_C}\right)^{\sigma^{CL}}$$

$$\frac{LE}{\overline{LE}} = \frac{FC}{\overline{FC}}\left(\frac{P_{FC}\overline{P}_{LE}}{\overline{P}_{FC} P_{LE}}\right)^{\sigma^{CL}}$$

$$\frac{TR}{\overline{TR}} = \frac{C}{\overline{C}}\left(\frac{P_C\overline{P}_{TR}}{\overline{P}_C P_{TR}}\right)^{\sigma^C}$$

$$\frac{CTRP}{\overline{CTRP}} = \frac{TR}{\overline{TR}}\left(\frac{P_{TR}\overline{P}_{CTRP}}{\overline{P}_{TR} P_{CTRP}}\right)^{\sigma^{TR}}$$

$$\frac{CTRN}{\overline{CTRN}} = \frac{TR}{\overline{TR}}\left(\frac{P_{TR}\overline{P}_{CTRN}}{\overline{P}_{TR} P_{CTRN}}\right)^{\sigma^{TR}}$$

$$\frac{NCAR}{\overline{NCAR}} = \frac{CTRN}{\overline{CTRN}}\left(\frac{P_{CTRN}\overline{P}_{NCAR}}{\overline{P}_{CTRN} P_{NCAR}}\right)^{\sigma^{on}}$$

$$\frac{OCAR}{\overline{OCAR}} = \frac{CTRN}{\overline{CTRN}}\left(\frac{P_{CTRN}\overline{P}_{OCAR}}{\overline{P}_{CTRN} P_{OCAR}}\right)^{\sigma^{on}}$$

$$\frac{NEV}{\overline{NEV}} = \frac{NCAR}{\overline{NCAR}}\left(\frac{P_{NCAR}\overline{P}_{NEV}(1-\bar{s}_{EV})}{\overline{P}_{NCAR} P_{NEV}(1-s_{EV})}\right)^{\sigma^{trpr}}$$

$$\frac{NICE}{\overline{NICE}} = \frac{NCAR}{\overline{NCAR}}\left(\frac{P_{NCAR}\overline{P}_{NICE}(1+\bar{t}_{ICE})}{\overline{P}_{NCAR} P_{NICE}(1+t_{ICE})}\right)^{\sigma^{trpr}}$$

$$\frac{OEV}{\overline{OEV}} = \frac{OCAR}{\overline{OCAR}}\left(\frac{P_{OCAR}\overline{P}_{OEV}(1-\bar{s}_{EV})}{\overline{P}_{OCAR} P_{OEV}(1-s_{EV})}\right)^{\sigma^{trpr}}$$

$$\frac{OICE}{\overline{OICE}} = \frac{OCAR}{\overline{OCAR}}\left(\frac{P_{OCAR}\overline{P}_{OICE}(1+\bar{t}_{ICE})}{\overline{P}_{OCAR}P_{OICE}(1+t_{ICE})}\right)^{\sigma^{trpr}}$$

Note that P_{OICE} (and same prices for new EV and ICE cars) are inclusive of other cost, such as insurance and maintenance cost.

$$CEEV = \overline{A_{CELE,OEV}}\frac{OEV}{\overline{OEV}}\left(\frac{P_{OEV}\overline{P}_{CELE}(1+\bar{t}_{VAT,CELE})}{\overline{P}_{OEV}P_{CELE}(1+t_{VAT,CELE})}\right)^{\sigma^{ceev}} + \overline{A_{CELE,NEV}}\frac{NEV}{\overline{NEV}}\left(\frac{P_{NEV}\overline{P}_{CELE}(1+\bar{t}_{VAT,CELE})}{\overline{P}_{NEV}P_{CELE}(1+t_{VAT,CELE})}\right)^{\sigma^{ceev}}$$

$$Y_{cpad} = \overline{A_{CPAD,OICE}}\frac{OICE}{\overline{OICE}}\left(\frac{P_{OICE}\overline{P}_{CPAD}(1+\bar{t}_{VAT,CPAD})}{\overline{P}_{OICE}P_{CPAD}(1+t_{VAT,CPAD})}\right)^{\sigma^{cpad}} + \overline{A_{CPAD,NICE}}\frac{NICE}{\overline{NICE}}\left(\frac{P_{NICE}\overline{P}_{CPAD}(1+\bar{t}_{VAT,CPAD})}{\overline{P}_{NICE}P_{CPAD}(1+t_{VAT,CPAD})}\right)^{\sigma^{cpad}}$$

$$\frac{ORICE}{\overline{ORICE}} = \theta_{old}^{ICE}\frac{OICE}{\overline{OICE}}\left(\frac{P_{OICE}\overline{P}_{ROICE}(1+\bar{t}_{C,ROICE})}{\overline{P}_{OICE}P_{ROICE}(1+t_{C,ROICE})}\right)^{\sigma^{cpad}}$$

$$\frac{NRICE}{\overline{NRICE}} = \theta_{new}^{ICE}\frac{NICE}{\overline{NICE}}\left(\frac{P_{NICE}\overline{P}_{RNICE}(1+\bar{t}_{C,RNICE})}{\overline{P}_{NICE}P_{RNICE}(1+t_{C,RNICE})}\right)^{\sigma^{cpad}}$$

$$\frac{OREV}{\overline{OREV}} = \theta_{old}^{EV}\frac{OEV}{\overline{OEV}}\left(\frac{P_{OEV}\overline{P}_{ROEV}(1+\bar{t}_{C,ROEV})}{\overline{P}_{OEV}P_{ROEV}(1+t_{C,ROEV})}\right)^{\sigma^{ceev}}$$

$$\frac{NREV}{\overline{NREV}} = \theta_{new}^{EV}\frac{NEV}{\overline{NEV}}\left(\frac{P_{NEV}\overline{P}_{RNEV}(1+\bar{t}_{C,RNEV})}{\overline{P}_{NEV}P_{RNEV}(1+t_{C,RNEV})}\right)^{\sigma^{ceev}}$$

$$\frac{I\_ICE_i}{\overline{I\_ICE_i}} = \theta_{i,old}^{ICE}\frac{OICE}{\overline{OICE}}\left(\frac{P_{OICE}\overline{P}_{ROICE}(1+\bar{t}_{C,ROICE})}{\overline{P}_{OICE}P_{ROICE}(1+t_{C,ROICE})}\right)^{\sigma^{cpad}} + \theta_{i,new}^{ICE}\frac{NICE}{\overline{NICE}}\left(\frac{P_{NICE}\overline{P}_{RNICE}(1+\bar{t}_{C,RNICE})}{\overline{P}_{NICE}P_{RNICE}(1+t_{C,RNICE})}\right)^{\sigma^{cpad}}$$

$$\frac{I\_EV_i}{\overline{I\_EV_i}} = \theta_{i,old}^{EV}\frac{OEV}{\overline{OEV}}\left(\frac{P_{OEV}\overline{P}_{ROEV}(1+\bar{t}_{C,ROEV})}{\overline{P}_{OEV}P_{ROEV}(1+t_{C,ROEV})}\right)^{\sigma^{ceev}} + \theta_{i,new}^{EV}\frac{NEV}{\overline{NEV}}\left(\frac{P_{NEV}\overline{P}_{RNEV}(1+\bar{t}_{C,RNEV})}{\overline{P}_{NEV}P_{RNEV}(1+t_{C,RNEV})}\right)^{\sigma^{ceev}}$$

In the same way for the cars in OTP, the supply of the old cars consists of the old cars in the previous period and new cars in the previous period (considering that some old cars are scrapped).

$$ORICE = (1-\delta)(ORICE_{-1} + NRICE_{-1})$$

$$OEV = (1-\delta)(OEV_{-1} + NEV_{-1})$$

The supply of the new cars (SCAR) is equal to the demand.

$$SCAR_{ICE} = NRICE$$

$$SCAR_{EV} = NREV$$

The supply of the new cars is adjusted such that the percentage change of the imported car prices is equal to the percentage change of the price of the rental value of the new cars. For example, the imported price of EVs go down in the future, the quantity of demand of EVs is increased, and the supply is increased such that the change of the imported price of EVs and the change of the price of the rental value becomes equal.

$$\frac{PM_{EV}}{\overline{PM}_{EV}} = \frac{P_{RNEV}}{\overline{P}_{RNEV}}$$

$$\frac{PM_{ICE}}{\overline{PM}_{ICE}} = \frac{P_{RNICE}}{\overline{P}_{RNICE}}$$

$$\frac{Y_l}{\overline{Y}_l} = \frac{CTRP}{\overline{CTRP}}\left(\frac{P_{CTRP}(1+\overline{t}_{VAT,l})\overline{P}_{P,l}}{\overline{P}_{CTRP}(1+t_{VAT,l})P_{P,l}}\right)^{\sigma_C^{CTRP}}$$

for $l = CRAI, CROA, CAIR, CBOA$

$$\frac{HOU}{\overline{HOU}} = \frac{C}{\overline{C}}\left(\frac{P_C\overline{P}_{HOU}}{\overline{P}_C P_{HOU}}\right)^{\sigma^C}$$

$$\frac{Y_{CHAW}}{\overline{Y}_{CHAW}} = \frac{HOU}{\overline{HOU}}\left(\frac{P_{HOU}\overline{P}_{P,CHAW}(1+\overline{t}_{VAT,CHAW})}{\overline{P}_{HOU}P_{P,CHAW}(1+t_{VAT,CHAW})}\right)^{\sigma^{HOU}}$$

$$\frac{ENE}{\overline{ENE}} = \frac{HOU}{\overline{HOU}}\left(\frac{P_{HOU}\overline{P}_{ENE}}{\overline{P}_{HOU}P_{ENE}}\right)^{\sigma^{HOU}}$$

$$\frac{Y_{CELE}}{\overline{Y}_{CELE}} = \frac{ENE}{\overline{ENE}}\left(\frac{P_{ENE}\overline{P}_{P,CELE}(1+\overline{t}_{VAT,CELE})}{\overline{P}_{ENE}P_{P,CELE}(1+t_{VAT,CELE})}\right)^{\sigma^{ENE}}$$

$$\frac{NELE}{\overline{NELE}} = \frac{ENE}{\overline{ENE}}\left(\frac{P_{ENE}\overline{P}_{NELE}}{\overline{P}_{ENE}P_{NELE}}\right)^{\sigma^{ENE}}$$

$$\frac{Y_l}{\overline{Y}_l} = \frac{NELE}{\overline{NELE}}\left(\frac{P_{NELE}\overline{P}_{P,l}(1+\overline{t}_{VAT,l})}{\overline{P}_{NELE}P_{P,l}(1+t_{VAT,l})}\right)^{\sigma_C^{NELE}}$$

for $l = CGAS, CPAH, CFAC, CDHE$

$$\frac{OTHER}{\overline{OTHER}} = \frac{C}{\overline{C}}\left(\frac{P_C\overline{P}_{other}}{\overline{P}_C P_{other}}\right)^{\sigma^C}$$

$$\frac{Y_l}{\overline{Y}_l} = \frac{OTHER}{\overline{OTHER}}\left(\frac{P_{other}\overline{P}_{P,l}(1+\overline{t}_{VAT,l})}{\overline{P}_{other}P_{P,l}(1+t_{VAT,l})}\right)^{\sigma_C^{other}}$$

for $l = other$

3.2.8. Government demand

$$\frac{G}{\overline{G}} = \frac{I_G}{\overline{I}_G} = \frac{A_{i,G}}{\overline{A}_{i,G}}$$

3.2.9. Demand for inputs in investment good production

$$\frac{I}{\overline{I}} = \frac{A_{i,I}}{\overline{A}_{i,I}}$$

3.2.10. Demand for domestic and imported capital

$$\frac{KD}{\overline{\overline{KD}}} = \frac{K}{\overline{\overline{K}}}\left(\frac{P_K \overline{P}_{KD}}{\overline{P}_K P_{KD}}\right)^{\sigma^K}$$

$$\frac{KM}{\overline{\overline{KM}}} = \frac{K}{\overline{\overline{K}}}\left(\frac{P_K \overline{P}_{KM}(1+\bar{t}_{KM})}{\overline{P}_K P_{KM}(1+t_{KM})}\right)^{\sigma^K}$$

3.2.11. Supply of capital to the domestic and foreign markets

$$\frac{KD}{\overline{\overline{KD}}} = \left(\frac{\overline{P}_{KS} P_{KD}}{P_{KS}\overline{P}_{KD}}\right)^{\eta^{KS}}$$

$$\frac{KX}{\overline{\overline{KX}}} = \left(\frac{\overline{P}_{KS} P_{KX}}{P_{KS}\overline{P}_{KX}}\right)^{\eta^{KS}}$$

3.3. Market clearing conditions

The following market clearing conditions must be fulfilled:

3.3.1. Armington good

$$A_i = \sum_{ii} A_{i,ii} + \sum_{c} A_{i,c} + A_{i,G} + A_{i,I} + A_{i,IG} + A_{i,ST}$$

3.3.2. Domestic investment

$$I = S$$

3.3.3. Capital

$$K^{new} + K^{old} + KM = KX + K$$

Note that KD is the supply for the transformation of domestic supply vs. export and the demand for the composite of domestic supply and import, and thus KD is cancelled out in this equation. K^{new} is new capital, and it depends on the size of the investment in the previous period.

$$\frac{K^{new}}{\overline{K}^{new}} = \frac{I_{-1}}{\overline{I}_{-1}}$$

K^{old} is old capital, and it is the capital in the previous period after depreciation.

$$K^{old} = (1 - \delta)(K^{old}_{-1} + K^{new}_{-1})$$

Then, the domestic supply of capital (net of trade) is equal to sectoral demand of capital.

$$K = \sum_i K_i$$

Note that the transport capital of OTP is separate, and that becomes sector specific capital as car capital.

3.3.4. Labour

$$\bar{L} - LE = \sum_i L_i$$

3.3.5. Balance of payments

$$\overline{BOP} = \sum_i (P_{X,i}X_i - P_{M,i}M_i) + P_{KX}KX - P_{KM}KM$$

3.4. Budget constraints

3.4.1. Household budget constraint

The representative household's total income consists of all primary factor income (from labour including leisure, capital and resources) and net taxes and transfers to the government:

$$PU \cdot U = \sum_{i,KV} P_{KV}KV_i(1 - t_I) + \sum_i P_L L_i(1 - t_I) + \sum_{xe} P_R R_{xe}(1 - t_{R,xe}) + \ transfer + P_{LE}LE$$

3.4.2. Government budget constraint

The government income consists of all tax income, plus transfers from the state pension fund abroad.

The tax income consists of taxes on output ($t_{Y,i}$), taxes on inputs ($t_{A,i,ii}$ and $t_{A,c,ii}$), value added tax on consumer goods (t_{VAT}), taxes on labour ($t_{L,i}$), resource tax ($t_{R,xe}$), import tax ($t_{IMP,i}$), income tax (t_I) and emission taxes ($t_{GHG,i}$). Note that $t_{GHG,i}$ is considered as ETS allowance price for ETS sectors, whereas it is considered as domestic emission tax for non-ETS sectors.

It is assumed that the government balances its income and expenditure, so all excess income is transferred to the representative household as lump-sum transfer (*transfer*).

$$P_G G = \sum_i P_{Y,i}Y_i t_{Y,i} + \sum_c P_{P,c}Y_c t_{VAT,c} + \sum P_{A,i}A_{i,ii}t_{A,i,ii} + \sum P_{A,i}A_{c,ii}t_{A,c,ii} + \sum_i P_{IMP,i}M_i t_{IMP,i} + + \sum_i P_L L_i t_{L,i}$$
$$+ \sum_{xe} P_R R_{xe} t_{R,xe} + \sum_{i,KV} P_{KV}KV_i t_I + \sum_i P_L L_i t_I + \sum_i Q_{GHG,i} t_{GHG,i} - transfer - \overline{BOP}$$

3.5. List of variables and parameters

Table 3.1 Sets

Set	Explanation	Name in GAMS-code and/or database
I	Industry (48 production sectors)	AGR, …, AVK
NEN	Non-energy goods (subset of i)	$NEN \notin \{ELE, OIL, GAS, COA\}$
Xe	Resource-constrained goods (subset of i)	In base version: $xe \in \{CRU, COA, GAS, ELE, AGR\}$ (other versions possible)
C	Consumption goods (27 consumption goods)	S61A – S61L plus S66 in the National Accounts; CFAB, CABT, …, GF in GAMS-code
Ctrn	Private transportation in final consumption (subset of consumption goods *c*)	CTEQ, CTEV, CPAD, CEEV
EV	Consumption of electric vehicles	MEV, CTEQ, TRD
ICE	Consumption of internal combustion engine vehicles	MIE, CTEV, TRD
Ctrp	Public transportation in final consumption (subset of consumption goods c)	CRAI, CROA, CAIR, CBOA
Chou	Housing services (subset of consumption goods *c*)	CHAW, CELE, CGAS, CPAH, CFAC, CDHE
Other	Subset of consumption goods *c*: "other goods", i.e. goods not related to housing, energy or transport	CFAB, CABT, CCAC, CFHR, CHEA, CCOM, CRAC, CEDU, CRAH, GF
KV	Capital varieties (materials (KMA), buildings (KBA), transport (KTR))	$KV \in \{KMA, KBA, KTR\}$
I	Investment good	S80 in the National Accounts
G	Final consumption of government	S64 and S65 in the National Accounts
IG	Government investment	S84 and S85 in the National Accounts
ST	Stock changes, statistical discrepancies	S87 in the National Accounts

Table 3.2 Share parameters

Parameter	Explanation
θ_i^l	Value share (in benchmark) of item l in the respective aggregate (i = in production of industry i, c = in consumption good)

Table 3.3 Elasticities

Parameter	Explanation	SNOW-name
σ_i^Y	Elasticity of substitution between KLE and MAT aggregates	esub_kle_m
σ_i^{MAT}	Elasticity of substitution between intermediate inputs from different industries (non-energy)	esub_m
σ_i^A	Elasticity of substitution between domestic and imported goods (Armington elasticity)	esub_dm
σ_i^{KLE}	Elasticity of substitution between KL and E	esub_e_va
σ_i^{KL}	Elasticity of substitution between K and L	esub_va
σ_i^K	Elasticity of substitution between different capital varieties for KV∈{KTR, KBA, KMA}	esub_k
σ_i^E	Elasticity of substitution between electricity and non-electricity in energy aggregate	esub_elec
σ_i^{NELE}	Elasticity of substitution between oil&gas and coal in the non-electricity aggregate	esub_c_go
σ_i^{LQD}	Elasticity of substitution between oil and gas	esub_g_o
η_i^T	Elasticity of transformation between domestic supply and exports of good I	etrn
η_i^K	Elasticity of transformation between domestic and foreign investment	e_kx
σ_i^K	Elasticity of substitution between domestic and imported capital	e_km
σ_{xe}^Y	Elasticity of substitution between resource and non-resource inputs	esub_r

Table 3.4 Substitution elasticities in consumption function

Parameter	Explanation	SNOW-name
σ^{CL}	Elasticity of substitution between consumption and leisure	esub_cl
σ^{U}	Elasticity of substitution between future and current consumption	esub_u
σ^{C}	Elasticity of substitution between housing and transportation and other consumption	esubh_s
σ_c^{other}	Elasticity of substitution between goods (except transportation and housing)	esubh_m
σ^{TRNT}	Elasticity of substitution between private and public transport aggregates	esubh_trnt
σ^{trpr}	Elasticity of substitution between EV and ICE in the private transport nest	esubh_trpr
σ^{CTRP}	Elasticity of substitution between different modes of public transport (road, rail, air, boat)	esubh_trpu
σ^{HOU}	Elasticity of substitution between dwellings and energy in dwellings	esubh_hou
σ^{ENE}	Elasticity of substitution between electricity and other energy sources in housing	esubh_ele
σ^{NELE}	Elasticity of substitution between non-electricity energy carriers in housing	esubh_nele
σ^{ncar}	Elasticity of substitution between new electric and conventional cars in private transportation in final consumption	esubh_ncar
σ^{ocar}	Elasticity of substitution between old electric and conventional cars in private transportation in final consumption	esubh_ocar
σ^{trel}	Elasticity of substitution between capital and fuel for electric cars in transportation in final consumption	esubh_trel
σ^{trco}	Elasticity of substitution between vehicles and fuel in the private transport nest	esubh_trco
σ^{on}	Elasticity of substitution between old and new cars	esubh_on
σ^{cpad}	Elasticity of substitution between CPAD (gasoline and diesel) and car	esubh_cpad
σ^{oilb}	Elasticity of substitution between fossil fuel product (OIL) and BIO	esubh_oilb
σ	Elasticity of substitution between new EV and ICE for OTP	esub_ncar
σ	Elasticity of substitution between old EV and ICE for OTP	esub_ocar
σ^{ceev}	Elasticity of substitution between electricity and the composite of car and O&M for electric cars in transportation in final consumption	esubh_ceev

Table 3.5 Price variables

Variable	Explanation
Production	
$P_{Y,i}$	Price of output of industry i (producer price)
$P_{DOM,i}$	Price of output delivered to the domestic market
$P_{IMP,i}$	Price of imported good (net of import tax)
$P_{X,i}$	Price of exports
$P_{A,i}$	Price of Armington good i
$P_{KLEM,i}$	Price of KLEM-aggregate
$P_{MAT,i}$	Price of intermediate input aggregate
$P_{KLE,i}$	Price of KLE-aggregate
$P_{KL,i}$	Price of KL-aggregate
$P_{K,i}$	Price of capital aggregate
P_{KV}	Price of different capital varieties KV (rental rate)
P_{L}	Price of labour (wage)
$P_{E,i}$	Price of energy aggregate
$P_{NELE,i}$	Price of non-electricity aggregate
$P_{LQD,i}$	Price of oil and gas aggregate
$P_{R,xe}$	Price of resource in the resource-based goods (xe)
P_{KS}	Price of capital supply
P_{KD}	Price of capital in the domestic market
P_{KM}	Price of capital imports
P_{KX}	Price of capital exports
P_{KA}	Price of new capital (Armington aggregate)
Production of consumption goods	
$P_{P,c}$	Production price of consumer good c (23 consumer goods)
$P_{MAT,c}$	Price of intermediate input aggregate in production of consumption goods
$P_{E,c}$	Price of energy aggregate in production of consumption goods
$P_{NELE,c}$	Price of non-electricity aggregate in production of consumption goods
$P_{LQD,c}$	Price of oil and gas aggregate in production of consumption goods
Consumption	
P_{U}	Price of aggregate utility
P_{FC}	Price of full consumption
P_{LE}	Price of leisure
P_{C}	Price of aggregate consumption good
P_{TR}	Price of transport aggregate in consumption
P_{CTRP}	Price of public transport aggregate in consumption
P_{CTRN}	Price of private transport aggregate in consumption
P_{NCAR}	Price of new cars in consumption
P_{OCAR}	Price of old cars in consumption
P_{ELE}	Price of electricity in consumption
P_{NEV}	Price of new EV in consumption
P_{NICE}	Price of new ICE in consumption
P_{OEV}	Price of old EV in consumption
P_{OICE}	Price of old ICE in consumption
P_{RNICE}	Rental price of new ICE
P_{ROICE}	Rental price of old ICE
P_{RNEV}	Rental price of new EV
P_{ROEV}	Rental price of old EV
P_{HOU}	Price of housing aggregate in consumption
P_{ENE}	Price of energy aggregate in housing in consumption
P_{NELE}	Price of non-electricity aggregate (in energy aggregate) in consumption
P_{other}	Price of “other” aggregate in consumption
Other	
P_{I}	Price of investment good
P_{S}	Price index of future consumptions (savings)
P_{G}	Price of government consumption
P_{IG}	Price of government investment

Table 3.5 Quantity variables

Variable	Explanation
Y_i	Production of sector i
A_i	Armington good i
$A_{ii,i}$	Intermediate input of good ii used in sector i
$A_{ii,c}$	Intermediate input of good ii used in production of consumption good c
$A_{ii,G}$	Intermediate input of good ii used in production of government consumption
$A_{ii,I}$	Intermediate input of good ii used in production of investment good I
$A_{ii,IG}$	Intermediate input of good ii used in production of government investment IG
$A_{ii,ST}$	Intermediate input of good ii in stock changes
MAT_i	Intermediate input aggregate in production of good i
KLE_i	Capital-labour-energy aggregate in sector i
KL_i	Capital-labour aggregate in sector i
K_i	Capital aggregate in sector i
KV_i	Capital input of different capital varieties in sector i
L_i	Labour input in sector i
E_i	Energy aggregate in sector i
$NELE_i$	Non-electricity aggregate in sector i
LQD_i	Oil and gas aggregate in sector i
$KLEM_i$	Capital-labour-energy-materials aggregate in sector i
R_{xe}	Resource input in resource-based sectors (xe)
Y_c	Consumption good c
MAT_c	Intermediate input aggregate in production of consumption good c
E_c	Energy aggregate in production of consumption good c
$NELE_c$	Non-electricity aggregate in production of consumption good c
LQD_c	Oil and gas aggregate in production of consumption good c
D_i	Deliveries to the domestic market
M_i	Imports
X_i	Exports
KD	Domestically invested capital
KM	Capital imports
KX	Capital exports
U	Utility index
FC	Full consumption
LE	Leisure
C	Aggregate consumption
I	Domestic investments (private)
S	Savings
G	Government consumption
I_G	Government investment
TR	Transport aggregate in consumption function
CTRP	Public transportation aggregate in consumption function
CTRN	Private transportation aggregate in consumption function
NCAR	New car in private transportation aggregate in consumption function
OCAR	Old car in private transportation aggregate in consumption function
NEV	New EV in private transportation aggregate in consumption function
NICE	New ICE in private transportation aggregate in consumption function
OEV	Old EV in private transportation aggregate in consumption function
OICE	Old ICE in private transportation aggregate in consumption function
$NRICE$	Rental value of new ICE
$ORICE$	Rental value of old ICE
$NREV$	Rental value of new EV
$OREV$	Rental value of old EV
I_ICE_i	Input for ICE car services
I_EV_i	Input for ICE car services
$SCAR_i$	Supply of new cars i=ICE, OTP
HOU	Housing aggregate in consumption function
ENE	Energy aggregate in housing in consumption function
NELE	Non-electricity aggregate in energy for housing in consumption function
OTHER	Aggregate of other goods and services in consumption function

Table 3.6 Taxes

Parameter	Explanation
$t_{Y,i}$	Output tax rate on industry i's product
$t_{A,i,ii}$	Input tax rate on intermediate inputs from industry ii used in industry i
$t_{A,c,ii}$	Input tax rate on intermediate inputs from industry ii used in production of consumption good c
$t_{IMP,i}$	Import tax rate of good i
$t_{L,i}$	Tax rate on labour
$t_{R,xe}$	Resource tax
$t_{VAT,i}$	Value added tax including other tax on consumption commodities (in the model VAT is separate)
t_{I}	Income tax
$t_{GHG,i}$	Emission tax or permit price of greenhouse gases
t_{ICE}	Tax rate on ICEs to finance the EV subsidy
s_{EV}	Implicit subsidy rate on EVs

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