1   **Appendices**

2   *Appendix A* Model description

3

4   **Demand and supply equations**

5   Aggregate output in industry b (Y_b) is composed of a hypothetical aggregate energy input

6   (AEN_b), aggregate intermediate input (AIN_b) and aggregate factor input (APR_b) according a

7   CES production function with constant returns to scale (see glossary at the end of this Appendix

8   for overview of variables, coefficients and sets). Intermediate inputs g in industry b ($IN_{b,g}$) are

9   transformed into an aggregate energy and aggregate intermediate input according to the CES

10   production functions with constant returns to scale. Labor ($PR_{b,1}$) and capital ($PR_{b,2}$) in

11   industry b are transformed into the aggregate factor input, using a CES production function

12   with constant returns to scale. Cost minimization yields CES demand functions for the

13   aggregate energy (A.1), aggregate intermediate (A.2), aggregate factor (A.3), energy (A.4),

14   intermediate (A.5) and factor inputs (A.6):

15

16   $AEN_b = f_{AEN_b}^{CES}(Y_b, WAEN_b, WAIN_b, WAPR_b)$ $\qquad \forall b \in B$ $\qquad$ (A.1)

17

18   $AIN_b = f_{AIN_b}^{CES}(Y_b, WAEN_b, WAIN_b, WAPR_b)$ $\qquad \forall b \in B$ $\qquad$ (A.2)

19

20   $APR_b = f_{APR_b}^{CES}(Y_b, WAEN_b, WAIN_b, WAPR_b)$ $\qquad \forall b \in B$ $\qquad$ (A.3)

21

22   $IN_{b,g} = f_{EN_{b,g}}^{CES}(AEN_b, \boldsymbol{WIN_g})$ $\qquad \forall b \in B, \forall g \in S_{en}$ $\qquad$ (A.4)

23

24   $IN_{b,g} = f_{IN_{b,g}}^{CES}(AIN_b, \boldsymbol{WIN_g})$ $\qquad \forall b \in B, \forall g \in S_{mat}$ $\qquad$ (A.5)

25

26 $$PR_{b,j} = f_{PR_{b,j}}^{CES}(APR_b, \boldsymbol{WPR_{b,j}}) \qquad\qquad \forall b \in B, \forall j \in J \qquad\qquad (A.6)$$

27

28 Supply of output g by industry b ($YY_{b,g}$) is proportional to the aggregate output (Y_b) by industry

29 b (A.7). Aggregation of outputs over industries gives domestic production (DP_g) of commodity

30 g (A.8):

31

32 $$YY_{b,g} = \delta_{b,g}^Y \times Y_b \quad \sum_{g \in G} \delta_{b,g}^Y = 1 \qquad\qquad \forall b \in B, \forall g \in G \qquad\qquad (A.7)$$

33

34 $$DP_g = \sum_{b=1}^B YY_{b,g} \qquad\qquad \forall g \in G \qquad\qquad (A.8)$$

35

36 Domestic production (DP_g) and imports (IM_g) are aggregated into total supply of commodity

37 g (SP_g) using a CES production function with constant returns to scale. This implies that the

38 Armington assumption is adopted (see Dervis et al., 1982, p.221). The total supply is then

39 divided into domestic use (DU_g) and exports (EX_g) using a CET product transformation

40 function with constant returns to scale. Cost minimization yields CES demand equations for

41 domestic production (A.9) and imports (A.10) and revenue maximization yields CET supply

42 equations for domestic use (A.11) and exports (A.12):

43

44 $$DP_g = f_{DP_g}^{CES}(SP_g, WDP_g, WIM_g) \qquad\qquad \forall g \in G \qquad\qquad (A.9)$$

45

46 $$IM_g = f_{IM_g}^{CES}(SP_g, WDP_g, WIM_g) \qquad\qquad \forall g \in G \qquad\qquad (A.10)$$

47

48 $$DU_g = f_{DU_g}^{CET}(SP_g, WDU_g, WEX_g) \qquad\qquad \forall g \in G \qquad\qquad (A.11)$$

49

50 $$EX_g = f_{EX_g}^{CET}(SP_g, WDU_g, WEX_g) \qquad\qquad \forall g \in G \qquad\qquad (A.12)$$

Total labour (j=1) and total capital (j=2) available in the economy (TPR_j) are divided into supply of labour ($PR_{b,1}$) and capital ($PR_{b,2}$) by industry using CET product transformation functions with constant returns to scale. Revenue maximisation yields supply functions for labor and capital, respectively (A.13):

$$PR_{b,j} = f_{pr_{b,j}}^{CET}(\overline{TPR_j}, \boldsymbol{WPR_{b,j}}) \qquad \forall b \in B, \forall j \in J \qquad (A.13)$$

Maximization of the CES utility functions yields CES demand equations for the private household (A.14) and public household (A.15):

$$CON_g = f_{con_g}^{CES}(EXP^{con}, \boldsymbol{WCON_g}) \qquad \forall g \in G \qquad (A.14)$$

$$GOV_g = f_{gov_g}^{CES}(EXP^{gov}, \boldsymbol{WGOV_g}) \qquad \forall g \in G \qquad (A.15)$$

The demand for investment goods (X_g^{inv}) is given by (A.16):

$$INV_g = \delta_g^{inv} \times INV \quad \sum_{g \in g} \delta_g^{inv} = 1 \qquad \forall g \in G \qquad (A.16)$$

Zero-profit conditions

The value of the disaggregated outputs by industry is equal to the value of the aggregate output produced by industry (A.17). The value of aggregate output equals the value of the aggregate energy input, aggregate intermediate input and aggregate factor input (A.18):

$$\sum_{g \in G} WDP_g\, Y_{b,g} = WY_b \times Y_b \qquad \forall b \in B \qquad (A.17)$$

76

$$WY_b Y_b = WAEN_b \times AEN_b + WAIN_b \times AIN_b + WAPR_b \times APR_b \qquad \forall b \in B \qquad (A.18)$$

78

79 The value of the aggregate energy input is equal to the value of the energy inputs by industry

80 (A.19). The value of the aggregate intermediate input equals the value of the intermediate inputs

81 by industry (A.20). The value of the aggregate factor input equals the value of labour and capital

82 by industry (A.21):

83

$$WAEN_b \times AEN_b = \sum_{g \in S_{en}} WIN_{b,g} \times IN_{b,g} \qquad \forall b \in B \qquad (A.19)$$

85

$$WAIN_b \times AIN_b = \sum_{g \in S_{mat}} WIN_{b,g} \times IN_{b,g} \qquad \forall b \in B \qquad (A.20)$$

87

$$WNAPR_b \times APR_b = \sum_{j=1}^{2} WPR_{b,j} \times PR_{b,j} \qquad \forall b \in B \qquad (A.21)$$

89

90 The value of total supply (SP_g) equals the sum of the value of domestic production and imports

91 (A.22) and the sum of the value of domestic use and exports by commodity (A.23):

92

$$WSP_g \times SP_g = WDP_g \times DP_g + WIM_g \times IM_g \qquad \forall g \in G \qquad (A.22)$$

94

$$WSP_g \times SP_g = WDU_g \times DU_g + WEX_g \times EX_g \qquad \forall g \in G \qquad (A.23)$$

96

97 The value of the supply of labour and capital equals the value of the total availability of labour

98 and capital, respectively (A.24).

99

$$\sum_{B \in b}(WPR_{b,j} \times PR_{b,j}) = WTPR_j \times \overline{TPR_j} \qquad \forall j \in J \qquad (A.24)$$

101

4

102   The value of the demand for individual investment goods equals the expenditure on investment

103   (A.25):

104

105    $\sum_{g \in G}(WINV_g \times INV_g) = WINV \times INV$ (A.25)

106

Margins

108   The value of demand/supply for margins per commodity (MAR_g) is assumed to form a share of

109   the value of the different demand categories and is given by (A.26).

110

111    $MAR_g = m_g^{sp} \times WDU_g \times DU_g + m_g^{sp} \times WEX_g \times EX_g \qquad \forall g \in G$ (A.26)

112

113   The total value of the margins is zero (A.27):

114

115    $\sum_{g \in G} MAR_g = 0$ (A.27)

116

Equilibrium conditions for commodities

118   Total domestic use equals intermediate, private household, public household and investment

119   demand (A.28):

120

121    $DU_g = \sum_{b \in B} IN_{b,g} + CON_g + GOV_g + INV_g \qquad \forall g \in G$ (A.28)

122

Price equations

124   Indirect taxes and margins drive a wedge between the demanders' and suppliers' price of

125   domestic use. This applies to commodities consumed by the private household (A.29), the

126   public household (A.30), as investment commodities (A.31), as intermediate inputs (A.32) and

127   as exports (A.33):

128

$$WCON_g = \left(1 + m_g^{sp} + t_g^{sp}\right) \times WDU_g \tag{A.29}$$

130

$$WGOV_g = \left(1 + m_g^{sp} + t_g^{sp}\right) \times WDU_g \tag{A.30}$$

132

$$WINV_g = \left(1 + m_g^{sp} + t_g^{sp}\right) \times WDU_g \tag{A.31}$$

134

$$WIN_g = \left(1 + m_g^{sp} + t_g^{sp}\right) \times WDU_g \tag{A.32}$$

136

$$WGEX_g = \left(1 + m_g^{sp} + t_g^{sp}\right) \times WEX_g \tag{A.33}$$

138

139 The price received for exports (A.34) and paid for imports (A.35) are equal to the world market

140 price times the exchange rate:

141

$$WGEX_g = \overline{WPEX_g} \times \overline{ER} \tag{A.34}$$

$$WIM_g = \overline{WPIM_g} \times \overline{ER} \tag{A.35}$$

144

145 Non-product related taxes are levied on the total value of labour and capital used by industry

146 (A.36):

147

$$WAPR_b = \left(1 + t_b^{apr}\right) \times WNAPR_b \tag{A.36}$$

149

150 **Income formation and distribution**

151 Tax revenue from product (PTX) and non-product related taxes ($NPTX$) and social contribution

152 ($SOCCON$) is given by equations A.37, A.38 and A.39, respectively:

153

$$PTX = \sum_{g \in S}\left(t_g^{sp} \times WDU_g \times DU_g + t_g^{sp} \times WEX_g \times EX_g\right) \tag{A.37}$$

155

$$NPTX = \sum_{b \in B}\left(t_b^{apr} \times WNAPR_b \times APR_b\right) \tag{A.38}$$

157

$$SOCCON = r_{soccon} \times LABI \tag{A.39}$$

159

160 Labour income ($LABI$), capital income ($CAPI$) and capital depreciation (DEP) are given by

161 equation A.40, A.41 and A.42 respectively:

162

$$LABI = WTPR_1 \times \overline{TPR_1} \tag{A.40}$$

164

$$CAPI = WTPR_2 \times \overline{TPR_2} \tag{A.41}$$

166

$$DEP = r_{capdep} \times CAPI \tag{A.42}$$

168

169 The income (I^{con}), expenditure EXP^{con} and savings (SAV^{con}) of the private household are

170 given by equations A.43, A.44 and A.45 respectively:

171

$$I^{con} = (1 - r_{soccon}) \times LABI + (1 - r_{capdep}) \times CAPI \tag{A.43}$$

173

$$EXP^{con} = (1 - s^{con}) \times I^{con} \tag{A.44}$$

175

$$SAV^{con} = s^{con} \times I^{con} \tag{A.45}$$

177

178   The income (I^{gov}), expenditure (EXP^{gov}) and savings (SAV^{gov}) of the public household are

179   given by equations A.46, A.47 and A.48, respectively:

180

181    $$I^{gov} = PTX + NPTX + SOCCON \qquad (A.46)$$

182

183    $$EXP^{gov} = (1 - s^{gov}) \times I^{gov} \qquad (A.47)$$

184

185    $$SAV^{gov} = s^{gov} \times I^{gov} \qquad (A.48)$$

186

187   Total savings (A.49) equal the sum of the savings of the private household, public household

188   and capital depreciation minus the surplus on the balance of trade (BBAR). As the balance of

189   trade is expressed in foreign price it must be multiplied by the exchange rate (ER):

190

191    $$SAV = SAV^{con} + SAV^{gov} + DEP - BBAR \times \overline{ER} \qquad (A.49)$$

192

193   The surplus on the balance of trade (A.50) equals:

194

195    $$BBAR = \sum_{g \in G} \left(\overline{WPEX_g} \times EX_g \right) - \sum_{g \in G} \left(\overline{WPIM_g} \times IM_g \right) \qquad (A.50)$$

196

197   The value of investment ($INVT$) equals the value of the savings (A.51) but also the value of the

198   investment commodities (A.52). Due to Walras' law, one equation must be dropped to keep the

199   model identified. In the operational model this is Equation A.52.

200

201    $$INVT = SAV \qquad (A.51)$$

202

203    $$INVT = WINV \times INV \qquad (A.52)$$

Price numéraire

An applied general equilibrium model is homogenous of degree zero. This model selects the exchange rate as price numéraire.

Environment

CO_2, CH_4, N_2O emissions of an industry ($EMIS_b$) equals the share (amount) of emissions (δ_b^{emis}) emitted by the industry ($Y_{b\ old}$).

$$\delta_b^{emis} = EMIS_{b\ old}/Y_{b\ old} \tag{A.53}$$

$$EMIS_b = \delta_b^{emis} \times Y_b \tag{A.54}$$

Welfare change

As a welfare measure, the Laspeyres index of real income change is taken. This index compares commodity bundles between two equilibria (e.g. before and after a policy change), using the prices of the initial equilibrium (A.55). This welfare measure allows for the calculation of the welfare effects of savings other than the private savings of which the underlying optimizing behaviour is not modelled explicitly (i.e., capital depreciation, government deficit and the balance of trade). Since savings are equal to investments, the bundle of investment commodities represent welfare derived from saving.

$$WELF =$$

$$\sum_{g \in S}\left(WCON_g^{old} \times CON_g^{old}\right)+\sum_{g \in S}\left(WGOV_g^{old} \times GOV_g^{old}\right) + \sum_{g \in S}\left(WINV_g^{old} \times INV_g^{old}\right) -$$

$$\sum_{g \in S}\left(WCON_g^{old} \times CON_g\right) - \sum_{g \in S}\left(WGOV_g^{old} \times GOV_g\right) - \sum_{g \in S}\left(WINV_g^{old} \times INV_g\right) \tag{A.55}$$

230 **Glossary**

231 **Variables:**

232 *Quantities*

233 Y_b aggregate output of industry b

234 AEN_b aggregate intermediate energy input in industry b

235 AIN_b aggregate intermediate materials input in industry b

236 APR_b aggregate factor input in industry b

237 $IN_{b,g}$ intermediate input g in industry b

238 $PR_{b,j}$ labour (j=1) and capital (j=2) in industry b

239 $YY_{b,g}$ output g of industry b

240 DP_g domestic production of commodity g

241 IM_g import of commodity g

242 SP_g total supply of commodity g

243 DU_g domestic use of commodity g

244 EX_g export of commodity g

245 $\overline{TPR_J}$ labour (j=1) and capital (j=2) endowment in the economy

246 CON_g consumer demand for commodity g

247 GOV_g government demand for commodity g

248 INV_g demand of investment good g

249 INV aggregate investment good

250 $EMIS_b$ emissions of industry b

251

252 *Prices (quantity symbols plus a W)*

253 $WAEN_b$ price of aggregate intermediate energy input in industry b

254 $WAIN_b$ price of aggregate intermediate materials input in industry b

255	$WAPR_b$	price of aggregate factor input including tax in industry b
256	$WNAPR_b$	price of aggregate factor input excluding the tax in industry b
257	WIN_g	price of intermediate input g
258	$WPR_{b,j}$	price of labour (j=1) or capital (j=2) used in industry b
259	WIM_g	price of import of commodity g
260	$\overline{WPIM_g}$	world market price of import of commodity g
261	WDP_g	price of domestic production of commodity g
262	WY_b	price of aggregate output of industry b
263	WSP_g	price of total supply of commodity g
264	WDU_g	price of domestic use of commodity g
265	WEX_g	price of export excluding taxes and margins of commodity g
266	$WGEX_g$	price of export including taxes and margins of commodity g
267	$\overline{WPEX_g}$	world market price of export of commodity g
268	$WCON_g$	price of commodity g demanded by the private household
269	$WGOV_g$	price of commodity g demanded by the public household
270	$WTPR_j$	price of labour (j=1) and capital (j=2) endowment in the economy
271	$WINV_g$	price of investment good g
272	$WINV$	price of aggregate investment good
273		
274	*Other*	
275	$\overline{ER}$	exchange rate
276	MAR_g	value of demand/supply of margins by commodity g
277	$LABI$	labour income
278	$CAPI$	capital income
279	DEP	capital depreciation

280	I^{con}	income of private household
281	I^{gov}	income of public household
282	EXP^{con}	expenditure of private household
283	EXP^{gov}	expenditure of public household
284	SAV^{con}	expenditure of private household
285	SAV^{gov}	expenditure of public household
286	SAV	total savings
287	$BBAR$	surplus on the trade balance (in foreign prices)
288	DEP	capital depreciation
289	$INVT$	value of the investment
290	PTX	value of the product related taxes
291	$NPTX$	value of the non-product related taxes
292	$SOCCON$	social contributions
293	$WELF$	welfare change

294

Fixed coefficients

296	δ_b^{emis}	coefficient dividing aggregate emissions by industry b
297	m_g^{sp}	margins for commodity g
298	t_g^{sp}	tax rate for product related taxes on commodity g
299	t_b^{apr}	tax rate for non-product related taxes in industry b
300	$\delta_{b,g}^{Y}$	coefficient dividing aggregate output into outputs g in industry b
301	δ_g^{inv}	coefficient dividing aggregate investment good into investment good g
302	s^{con}	savings rate of the private household
303	s^{gov}	savings rate of the public household
304	r_{soccon}	share of labour income that goes to social contributions

305   r_{capdep} capital depreciation as share of capital income

306

Sets and subsets:

308   G: goods, g = 1 to 60

309   B: industries, b = 1 to 60

310   J: factors, j = 1 (labour) j = 2 (capital)

311   $S_{en} \subset G$:   subset energy commodities: g = 24,25

312   $S_{mat} \subset G$:   subset materials: g = 1,…,23,26,…,60

313

Miscellaneous

315 gov = public household; con = private household; inv = investment; en = energy; old = base

316 year value; CES = Constant Elasticity Substitution; CET = Constant Elasticity of

317 Transformation

318

319 **Bold** printed variables represent a vector; variables with a bar represent exogenous variables.

320

321 *Appendix B* Aggregation level of commodities and industries in Supply-Use tables

CPA/NACE code	Commodity/Industry
A01	Crop and animal production, hunting and related service activities
A02	Forestry and logging
A03	Fishing and aquaculture
B	Mining and quarrying
C10_12	Manufacture of food products, beverages and tobacco products
C13_15	Manufacture of textiles, wearing apparel and leather products

13

C16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
C17	Manufacture of paper and paper products
C18	Printing and reproduction of recorded media
C19	Manufacture of coke and refined petroleum products
C20	Manufacture of chemicals and chemical products
C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
C22	Manufacture of rubber and plastic products
C23	Manufacture of other non-metallic mineral products
C24	Manufacture of basic metals
C25	Manufacture of fabricated metal products, except machinery and equipment
C26	Manufacture of computer, electronic and optical products
C27	Manufacture of electrical equipment
C28	Manufacture of machinery and equipment n.e.c.
C29	Manufacture of motor vehicles, trailers and semi-trailers
C30	Manufacture of other transport equipment
C31_32	Manufacture of furniture; other manufacturing
C33	Repair and installation of machinery and equipment
D35-1	Biobased energy
D35-2	Non-biobased energy
E36	Water collection, treatment and supply
E37_39	Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services
F	Construction

G	Wholesale and retail trade
H49	Land transport and transport via pipelines
H50_51	Water and Air transport
H52	Warehousing and support activities for transportation
H53	Postal and courier activities
I	Accommodation and food service activities
J58	Publishing activities
J59_60	Motion picture, video and television program production, sound recording and music publishing activities; programming and broadcasting activities
J61	Telecommunications
J62_63	Computer programming, consultancy and related activities; information service activities
K64	Financial service activities, except insurance and pension funding
K65	Insurance, reinsurance and pension funding, except compulsory social security
K66	Activities auxiliary to financial services and insurance activities
L68	Real estate activities
M69_70	Legal and accounting activities; activities of head offices; management consultancy activities
M71	Architectural and engineering activities; technical testing and analysis
M72	Scientific research and development
M73	Advertising and market research
M74_75	Other professional, scientific and technical activities; veterinary activities
N77	Rental and leasing activities
N78	Employment activities

N79	Travel agency, tour operator reservation service and related activities
N80_82	Security and investigation activities; services to buildings and landscape activities; office administrative, office support and other business support activities
O	Public administration and defense; compulsory social security
P	Education
Q86	Human health activities
Q87_88	Social work activities
R90_92	Creative, arts and entertainment activities; libraries, archives, museums and other cultural activities; gambling and betting activities
R93	Sports activities and amusement and recreation activities
S94	Activities of membership organizations
S95	Repair of computers and personal and household goods
S96_T	Other personal service activities

322

323 *Appendix C* Industries ranked according to the largest shares in supply and use of biobased

324 energy commodities

Suppliers of Energy commodities*	Users of Energy commodities**
Forestry and logging	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
Fishing and aquaculture	Manufacture of chemicals and chemical products
Manufacture of machinery and equipment n.e.c.	Residential care activities and social work activities without accommodation

	Sewerage, waste management, remediation activities
Rental and leasing activities	
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	
Manufacture of chemicals and chemical products	
Manufacture of furniture; other manufacturing	
Retail trade, except of motor vehicles and motorcycles	

325 * 90%<

326 **30%<

327 Source: author`s calculations based on Eurostat, 2021

328

329 *Appendix D* Substitution (sigma) and transformation (omega) elasticities

Symbol	Function	Value
SIGMAY (B)	CES for output	0.4
SIGMAPR (B)	CES for aggregate primary input	0.4
SIGMAE (B)	CES for aggregate energy input	1.5
SIGMAX (B)	CES for aggregate intermediate input	0.4
SIGMADOMS (G)	CES for domestic supply	1.5
OMEGADOMD (G)	CET for domestic demand	-1.5

330

331