# The EMEC model: Version 2.0

Göran Östblom and Charlotte Berg

# Sammanfattning[*]

Konjunkturinstitutets allmän jämviktsmodell EMEC (Environmental Medium term EConomic model) har under 10 års tid kontinuerligt utvecklats och använts i utredningssammanhang. Den nya modellversionen, EMEC 2.0, som beskrivs i föreliggande uppsats, är en väsentlig utveckling av en tidigare modellversion. Det är framför allt transportefterfrågans bestämning som har utvecklats i modellen så att både hushåll och företag nu har möjlighet att substituera mellan skilda transportslag. Detta har också medfört att den tidigare samfärdselsektorn har delats upp i flera transportslag och att hushållens privata transporter delats upp på arbetsresor och fritidsresor. Elproduktion och värmeproduktion har också delats upp i separata sektorer. I syfte att förbättra representationen av energiintensiva sektorer bildar metallverk och jord - och stenvaruindustri egna sektorer tillika med att läkemedelsindustri inte längre ingår i kemisk industri utan bildar en egen sektor. Det är också möjligt att studera fördelningseffekter av miljöpolitik genom att hushållen fördelats på sex grupper efter inkomst och regional hemvist.

Modellen har 26 näringslivssektorer och en offentlig sektor. Företag, hushåll och offentlig sektor efterfrågar 33 sammansatta varor och tjänster som insatsvaror samt för investeringar och privat konsumtion. De sammansatta varorna framställs av importerade varor och inhemskt producerade varor som även kan exporteras. Näringslivet och offentlig sektor använder dessutom arbetskraft, realkapital, transporter och energi som insatsfaktorer i produktionen av varor och tjänster. Näringslivets aktivitet och hushållens konsumtion medför miljöföroreningar. Det är i första hand olika slags förbränning som medför utsläpp av koldioxid, svaveldioxid, kväveoxider och partiklar men även produktionsprocesser bidrar till luftutsläppen. Tilldelning av utsläppsrätter omfattar anläggningar inom järn- och stålindustri, raffinaderier, massa- och pappersindustri, mineralindustri samt inom el- och värmeproduktion. I modellen förekommer emellertid inte uppgifter om enskilda anläggningar så därför räknas all produktion i aktuella sektorer till den s.k. handlande sektorn.

De ekonomiska aktörerna reagerar på priser inklusive skatter genom att företagen byter till relativt billigare produktionsfaktorer och genom att hushållen byter till relativt billigare konsumtionsvaror. Modellens långsiktiga karaktär innebär att marknadens aktörer hinner anpassa sig fullt ut till de prisförändringar som äger rum när ekonomin rör sig mot ett nytt jämviktsläge. Detta antas vara en acceptabel förutsättning på 10–20 års sikt. Hur stora anpassningarna blir vid en given prisförändring beror på aktörernas känslighet för prisförändringar. Aktörernas priskänslighet är en bedömningsfråga grundad på ett mycket varierande empiriskt underlag. Styrkan i den ekonomiska tillväxten styrs i modellen av tillgången på produktionsfaktorer, såsom arbetskraft och kapital, och på teknisk utveckling mätt som arbetsproduktivitet. Tillgången på arbetskraft, priset på kapital och arbetsproduktivitetens utveckling är exogent givna utanför modellen. Det är också möjligt att låta begränsningar för miljöutsläpp inverka på tillväxtens storlek och inriktning.

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[*]In Swedish

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## Abstract

The present paper introduces a new version of an applied general equilibrium model of the Swedish economy: *E*nvironmental *M*edium Term *Ec*onomic Model (EMEC). The model is used at NIER for analysing economic implications for households and firms of the Swedish environmental policy. The economy and the environment interact in the model and thus, we can analyse the economic implications of various environmental policy measures, such as a $CO_2$-tax, a $CO_2$-ceiling and $CO_2$-trading. The model captures also ancillary benefits of climate policy for $NO_x$, $SO_2$, PM10 and PM20. This new version of EMEC, in addition, analyses the effects of road user charges and the economic impact of environmental policy measures on six types of households, as transport demand is represented in a much more detail and as households are distributed, by disposal income and residence. Furthermore, the model distinguishes 26 industries, 33 composite commodities, 26 consumer goods, two kinds of labour and eight pollutants. The model produces results for endogenous variables, which can be interpreted fully in terms of the model's theory, data and the assumptions underlying the exogenous variables.

***Keywords:*** CGE-model; Sectors; Pollutants; Factors of production; Substitution; Sweden

# 1.     Introduction

EMEC[1] is a computable general equilibrium (CGE) model of the Swedish economy developed and maintained by the National Institute of Economic Research (NIER) for analysis of the interaction between the economy and the environment. The present paper reports on a new version of this model.[2] The model was used for the first time in the Swedish Medium Term survey (MTS) of 1999/2000 (reported in SOU 2000:7) but also in the MTS of 2003/04 (reported in SOU 2004:19). It was used also for analysing the economic implications of the Kyoto agreement on $CO_2$ restrictions (reported in SOU 2000:23 and by Nilsson (2002)), for analysis of economic effects on Sweden of EU's system of emission trading (reported in SOU 2005:10, SOU 2003:60 and by Östblom (2003a), (2003b), (2004a)) and for analysis of Sweden's climate strategy (kontrollstation 2004) reported in (Sveriges klimatstrategi) and by Östblom (2004b). Sulphur abatement cost functions were introduced in the model by Östblom (2002). Also, a feedback effect on health and labour productivity of nitrogen oxide pollution was introduced by Östblom and Samakovlis (2004).

The political will of correcting for the externalities of road transports are growing in the EU and the implementations of road user charges (kilometre taxes) are discussed in many EU countries. Also, the Swedish Road Tax Commission has proposed a kilometre tax for heavy trucks in Sweden (reported in SOU 2004:63). To analyse the economic effects of a kilometre tax, therefore, transport demand of the household sector as well as transport demand of the industry sector are represented in a much more detail in the present version of the model (EMEC 2.0).[3]

EMEC is a static CGE-model with 26 industries and 33 composite commodities and a public sector producing a single commodity. Produced goods and services are exported and used together with imports to create composite commodities for domestic use. Composite commodities are used as inputs by industries and for capital formation. In addition, households consume composite commodities and there are 26 consumer commodities.

Production requires primary factors (two kinds of labour and capital) as well as inputs of materials, transports and energy. The use of fuel inputs in current production and households' fuel consumption emit carbon dioxide ($CO_2$), carbon monoxide (CO), methane ($CH_4$), sulphur dioxide ($SO_2$), nitrous oxide ($N_2O$), nitrogen oxides ($NO_x$) and particulate matter (PM10, PM25).

The supply of each type of labour is exogenous for the economy as a whole, while capital is supplied to the economy at a given price. All factors can move freely between domestic sectors. Perfect competition and no economies of scale in production are assumed for all markets. The small country assumption is adopted for tradable goods and the problem of overspecialization is handled by the Armington assump-

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[1] Environmental medium term economic model.

[2] CGE modelling has been used by applied economists for a long time and are increasingly influential in policy making. A thorough review of the field is given by Dixon, P. and Paramenter, B.R. (1996) and an exellent guiding in how to construct a CGE-model is presented by Dixon, P., Paramenter, B.R, Powell, A. and Wilcoxen, P (1992). The use of CGE models is now a well established tool for environmental policy analysis as reviewed by Bergman, L. (2005). For a model of EU countries see e.g. European commission (1995) and for Swedish models see Östblom, G. (1999) and Hill, M. (2001).

[3] CGE modelling of transport demand was performed by e.g. Kremers, H., Nijkamp, P., and Rietvald P. (2002), Steininger, K. (2002), Johnsson, R. (2003) and Nilsson, C. (2004).

tion for imports and by a relative price dependent supply function for exported goods. [4]

Households are distributed into six subgroups by disposal income and by place of residence. The model runs with exogenous interest rate and is closed with an exogenous ratio of the current account. The foreign price level is chosen as numeraire.

The use of energy by firms or households is subject to an energy tax and pollution taxes.[5] Tax exemptions due to the use of $CO_2$ permits or for other reasons are reflected in the estimated tax rates. Consumer goods are also subject to a value-added tax as well as other indirect taxes. The use of labour is subject to social security fees and households pay income tax on labour income. Firms and households react on prices, including taxes, and adjust their mix of inputs or their bundle of consumer goods by substituting away from the relatively dearer input or good.

The representative firm is assumed to choose an optimal mix of two types of labour and an optimal mix of energy in three stages. The firm, then, decides upon the mix of labour and physical capital in the creation of value added as well as the mix of energy and material in the creation of energy-material input. The various outputs and inputs must be transported, and the firm chooses an optimal transport solution (which allows for the use of several transport modes) in two steps. An optimal mix of value added and energy-material input is chosen at the highest level, to produce the firm's output. Another kind of substitution relates to goods of the same classification. Domestic goods are non-perfect substitutes for foreign goods in domestic as well as foreign use; i.e. in imports as well as in exports.

The motives for modelling transport demand in EMEC are discussed in section 2 which follows after this introduction. The aggregates and data of the model are presented in Section 3. All equations are given in Section 4. Calibration procedures and choice of parameter values are briefly discussed in Section 5. Section 6 concludes the paper. Technical definitions of goods and factors are given in Appendix A, which also includes a list of variable names. Appendix B shows the equations for the CES price aggregation of various consumer commodities.[6] Appendix C is a short introduction to CES aggregation.

# 2  The modelling of transport demand

Freight transports by roads, measured as transport work (tonne-km), as well as the $CO_2$ emissions of these transports increased in relation to economic growth (GDP), as concluded by Åhman (2004) for Sweden 1980-2002. Personal transports by roads, measured as transport work (person-km), as well as the $CO_2$ emissions of these transports also increased but less than GDP or private consumption, according to SIKA (2005). The increasing external costs of road transports are becoming less accepted in many EU countries and the will of correcting for the externalities of road transports are growing among member states as discussed by Hammar (2006a). Road user charges (kilometre taxes) have been, or are discussed to be, implemented in many EU countries. The Swedish Road Tax Commission has proposed a kilometre tax for heavy trucks in Sweden, and the design of such a tax is discussed by Hammar

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[4] Domestic goods of the same statistical classification are non-perfect substitutes for imported goods, which are of a different origin. This treatment of imports was pioneered by Armington (1969).

[5]  Also, the levels of various emissions can be bounded in the model to give the corresponding shadow prices of emission.

[6] Constant Elasticity of Substitution (CES).

(2006b). Also, transportation is subject to other taxes and fees, which aim at reducing its externalities and emissions to the air.

To capture the economic effects of a kilometre tax within a CGE framework, the transport demand of households and firms must be modelled with the options of adjusting to the changes of transportation costs. The present version of EMEC exhibits such adjustment mechanisms when the households and firms choose among a number of transportation modes for work trips and leisure trips, as well as firms' transportations of inputs and outputs.

Households gain utility of consumption and work trips. The utility function is separable in the utility of work trips and the utility of consumption. The utility of work trips is set in proportion to households' labour supply. Households maximize the utility of consumption and work trips according to a budget constraint. The utility of leisure trips is derived from the utility of consumption. A variety of transportation modes differing in transportation costs can be used for work trips and leisure trips. Equations of the households' transport demand were derived by Nilsson (2004) and are presented in section 4.1.

The flows of commodities relate to production and consumption of commodities in the economy, and thus economic activity brings about demand for carriers of commodity flows. Production demands materials and energy inputs, which are substitutes for labour and capital in the model. Firms are cost minimizing in the choice of labour, capital, energy, materials and various transport modes for producing outputs. In the model, thus, firms adapt to price changes, due to e.g. a kilometre tax, when choosing among a number of transport modes for the commodity flows. Equations of the firms' transport demand are presented in section 4.2.

# 3         Aggregates and data of the model

The database of *EMEC* includes input-output data for 69 business sectors, 85 commodities, 150 consumer goods, and seven educational groups of labour, a stock of capital, six groups of households, 33 energy carriers and 8 pollutants, which permits a wide range of aggregation possibilities. Data are aggregated to more manageable dimensions, and the present model distinguishes 27 producing sectors - 26 business sectors and a public sector: 1. Agriculture, 2. Fishery, 3. Forestry, 4. Mining, 5. Other industries, 6. Mineral products, 7. Pulp and paper mills, 8. Drug industries, 9. Other chemical industries, 10. Iron and Steel industries. 11. Non-iron metal industries, 12. Engineering, 13. Petroleum refineries, 14. Electricity supply, 15. Steam and hot water supply, 16. Gas distribution, 17. Water and sewage, 18. Construction, 19. Rail road transports, 20. Road goods transports, 21. Road passenger transports, 22. Sea transports, 23. Air transports, 24. Other transports, 25. Services, 26. Real estate and a public sector. The 27 sectors produce 33 commodities in fixed proportions and two commodities are not produced but imported (coal and crude petroleum). The model distinguishes between skilled and unskilled labour. Aggregation schemes, definitions and data sources are given in Appendix A.

The relatively high intensity of skilled labour in the public sector implies that different growth rates for public services[7] may have substantial effects on the market for skilled labour and indirectly on the competitiveness of the most important exporting sectors of the model economy. The potential competition for resources is even more

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[7] Note that in the National Accounts, productivity growth is set to zero in the public sector.

evident in the market for real capital between the exports oriented capital-intensive sector, the letting of dwellings and energy production.

**Figure 1 Flows of commodities, factors and emissions in *EMEC*\***
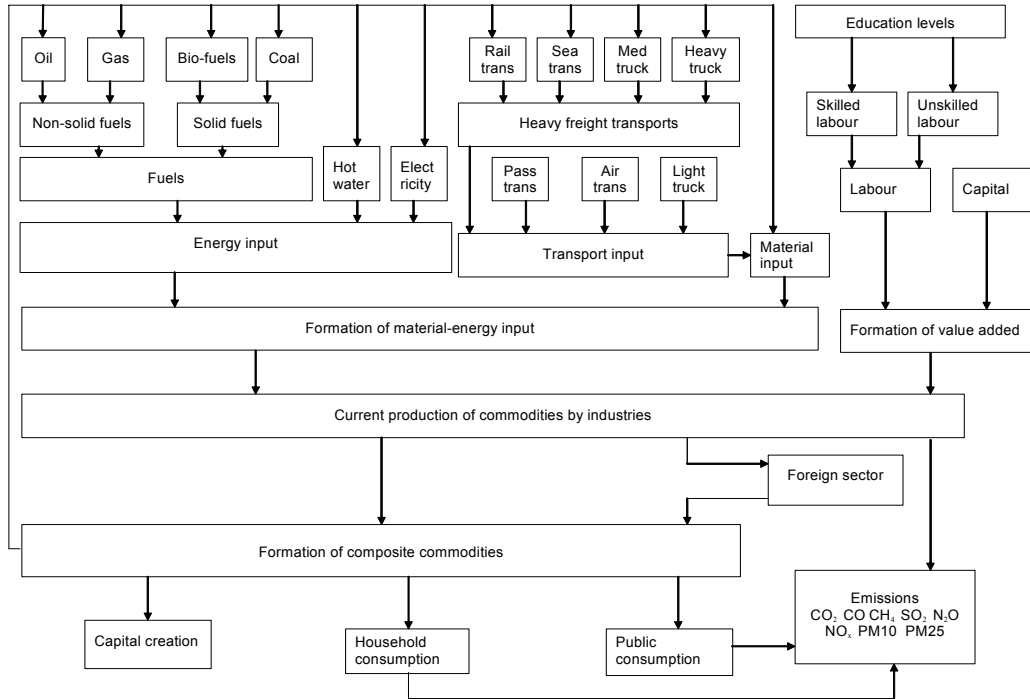


*The arrows indicate the direction of flows.

# 4 Equations of the model

Besides households and firms, the model economy includes also a public sector and a foreign sector. The economic agents use resources such as labour, capital, energy and the environment to achieve wealth. Households maximize utility subject to an income restriction, firms maximizes profit subject to resources restrictions, disposal of public services are subject to a budget constraint and the foreign sector's import and export activities are govern by an exogenously given trade balance. The demands and supplies of commodities and resources are cleared by market prices and there are also shadow prices for emitting pollutions the air. All of these activities are taken care of in the model by a number of equations for final demands, input demands, total domestic demand an output, emissions of pollutants, price setting, market clearing and emission constraints.

## 4.1 Final demands

*Private consumption*

The model has six representative consumers or consumer groups, h, maximizing the utility of consumption and work trips. The six consumer groups are: low income group in big city areas, high income group in big city areas, low income group in population centres, high income group in population centres, low income group in sparsely populated areas high income group in sparsely populated areas The utility

functions (*UTOT$_b$*) are four-level constant elasticity of substitution (CES) functions, and figure 2 depicts the nested structure of the utility function for a household. [8]

At the top level of the consumption tree, utility is separable into work trips and consumption of goods and services. Work trips are a perfect complement to labour supply, and therefore households choose among various transport modes, according to their preferences, in order to fulfil the amount of work trips needed in proportion to their supply of labour.

At the second level of the consumption tree, the consumption of goods and services are separated into three main categories of consumer goods: goods related to housing (i.e. rents and energy), leisure trips and a third category of all other goods and services. The housing commodity is a CES-aggregate of rents and heating, which in turn is a CES-aggregate of fuel, district heating and electricity. Fuel is a CES-aggregate of the various fuels used for combustion (excluding motor fuels), i.e. oil, gas, coal, bio-fuels. Leisure trips are a composite of long leisure trips and short leisure trips. Finally, the composites long leisure trips and short leisure trips are CES-aggregates of the various transport modes: bus, boat, rail, air and car (petrol in figure 2). The third main category constitutes the CES function for consumption of all other goods and services.

**Figure 2 Consumer utility function.**



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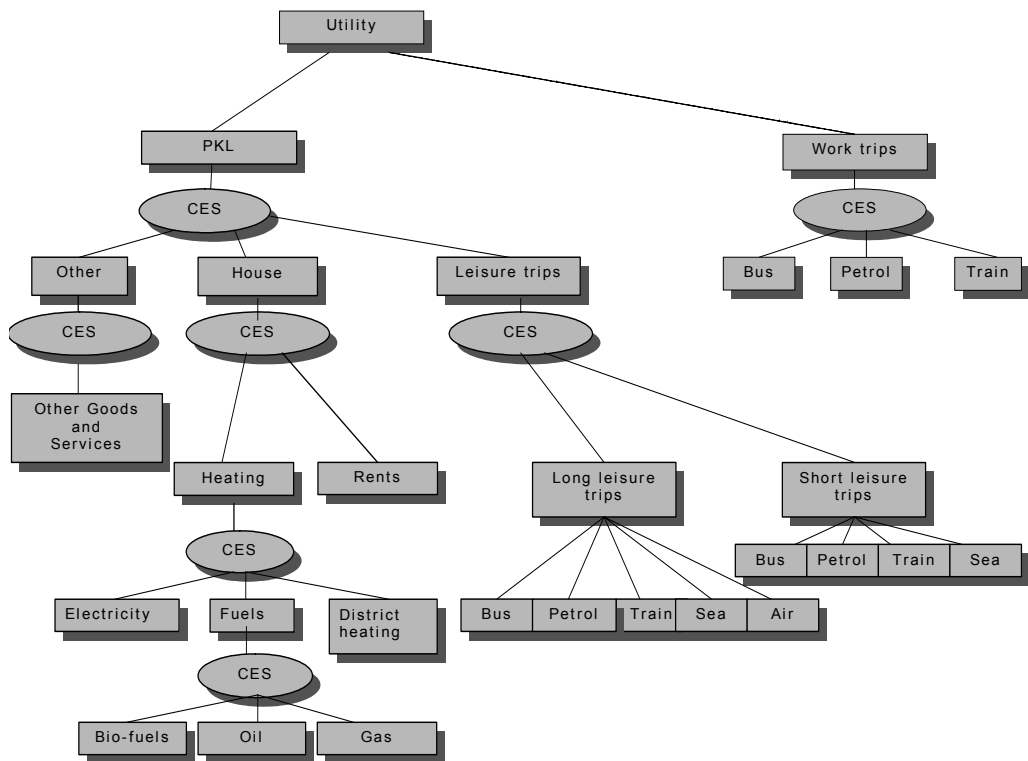
[8] The CES function is frequently used in applied general equilibrium modelling to depict the behaviour of firms and households. The CES utility function and its dual expenditure function are used to model households' substitution and demand of commodities. For a short introduction to the use of CES functions for modelling firms' and households' behaviour, see Appendix C.

The budget constraint of households states that consumption expenditures must equal the sum of primary factor (labour and capital) incomes, public transfers net of private investments and payment on foreign debt. The income of labour differs between the six household groups in accordance with benchmark data. We assume, due to the lack of better data, that capital income, transfers and private investments take the same average shares of expenditures for all household groups. Payment on foreign debt is calculated as a residual, equal to consumption expenditures and savings (investments) less factor incomes and transfers.

The consumer allocates his total resources between the need for work trips $WORK_h$, and the consumption of goods and services other than work trips $PKL_h$.

$$UTOT_h = PKL_h + WORK_h. \tag{1}$$

Differentiation of the minimum expenditure per unit of work trips results in households demand for different types of transport modes *trw* (bus, train and private owned cars) used for work trips $HC_{h,trw}$.

$$HC_{h,trw} = atrw_{h,trw}^{swork_h-1} \left( \frac{PWORK_h}{PHCS_{h,trw}} \right)^{swork_h} \cdot WORK_h. \tag{2}$$

The variable $WORK_h$ is the aggregate of work trips, and the corresponding price is denoted $PWORK_h$. The variable $PHCS_{h,trw}$ is the price (including taxes), of various transport modes, *trw*. The substitution elasticity is denoted $swork_h$ and $atrw_{h,trw}$ is a calibration constant.

The aggregate of work trips and labour are perfect complements; and thus the aggregate of work trips is in proportion to the supply of labour ($LTOT_h$) for each household group:

$$WORK_h = \beta_h \cdot LTOT_h. \tag{3}$$

Where $\beta_h$ is the proportion of work trips demanded for a unit of labour supply. [9]

The variable $PKL_h$ is a CES aggregate of leisure trips, housing services and other consumer goods and services, i.e. the variables $FRITRANS_h$, $HOUSE_h$ and $OVR_h$, respectively, at the highest level of aggregation.

$$PKL_h = \left[ \left( ak1_h \cdot FRITRANS_h \right)^{\frac{spk-1}{spk}} + \left( ak2_h \cdot HOUSE_h \right)^{\frac{spk-1}{spk}} + \left( ak3_h \cdot OVR_h \right)^{\frac{spk-1}{spk}} \right]^{\frac{spk}{spk-1}} \tag{4}$$

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[9] The proportion $\beta$ is calibrated from base year data and rereflects the share of overtime work in labour supply for the base year. It could also be assumed that $\beta$ decreases with labour supply as there are reasons to belive that the proportion of overtime work increases with labour supply. This assumption, as well as assumptions of other changes in the composition of labour supply compared to base year data, however, could be taken care of by letting $\beta$ take values different from the calibrated value.

Leisure trips, $FRITRANS_h$, is a composite of long leisure trips, $LONG_h$, and short leisure trips, $SHORT_h$, which are undertaken by use of the various transport modes, *trs*, including bus transports, boat transports, rail transports and car transports.

Differentiation of the minimum expenditure per unit of short leisure trips demanded, $SHORT_h$ gives the demand of transport modes for short leisure trips, $HC_{h,trs}$ according to the equation (5) at the third level of aggregation. Similarly, differentiation of the minimum expenditure per unit of long leisure trips demanded $LONG_h$, gives the demand of transport modes, *trh* (bus, train, air, sea and car), for long leisure trips $HC_{h,trh}$ according to equation (6) at the third level of aggregation.

$$HC_{h,trs} = atrs_{h,trs}^{sshort_h - 1} \left( \frac{PSHORT_h}{PHCS_{h,trs}} \right)^{sshort_h} \cdot SHORT_h. \tag{5}$$

$$HC_{h,trh} = atrh_{h,trh}^{slong_h - 1} \left( \frac{PLONG_h}{PHCS_{h,trh}} \right)^{sholi_h} \cdot LONG_h. \tag{6}$$

The variables $PSHORT_h$ and $PLONG_h$ are the corresponding prices for short and long leisure trips, respectively. The variables $PHCS_{h,trs}$ and $PHCS_{h,trh}$ are the prices including taxes for various transport modes. The substitution elasticity is denoted $sshort_h$ and $slong_h$, respectively, whereas $atrs_{h,trs}$ and $atrh_{h,trh}$ are the calibration constants.

The demand of short leisure trips and long leisure trips, the variables $SHORT_h$ and $LONG_h$ in equations (7) and (8) respectively, is given by differentiation of the minimum expenditure per unit of aggregate leisure trips demanded, $FRITRANS_h$, with the corresponding price $PFRITRANS_h$, at the second level of aggregation.

$$SHORT_h = ashort_h^{sfritrans_h - 1} \left( \frac{PFRITRANS_h}{PSHORT_h} \right)^{sfritrans_h} \cdot FRITRANS_h, \tag{7}$$

$$LONG_h = along_h^{sfritrans_h - 1} \left( \frac{PFRITRANS_h}{PLONG_h} \right)^{sfritrans_h} \cdot FRITRANS_h. \tag{8}$$

The substitution elasticity is $sfritrans_h$ and the calibrated constants are $ashort_h$ and $along_h$.

The variable for housing services $HOUSE_h$ is a CES aggregate of other housing services (rents), $HC_{h,rents}$ and heating $HEAT_h$. The last variable in turn is a CES aggregate of fuels, electricity and district heating, i.e. the variables $FUEL_h$,

$HC_{h,hel}$ and $HC_{h,heat}$, respectively. The households demand of various fuels, the variable $HC_{h,f}$ (the index f denotes oil, gas and bio-fuel), is given by differentiation of the minimum expenditure per unit of fuel aggregate $FUEL_h$ at the lowest level of aggregation.

$$HC_{h,f} = afuel_{h,f}^{sfuel_h - 1} \left( \frac{PFUEL_h}{PHCS_{h,f}} \right)^{sfuel_h} \cdot FUEL_h. \tag{9}$$

The corresponding price is $PFUEL_h$, the variable $PHCS_{h,f}$ is the prices of various fuels, $sfuel_h$ is the substitution elasticity and $afuel_{h,f}$ is a calibration constant.

The households' demand of the various energy carriers used for heating, fuels $FUEL_h$, electricity $HC_{h,hel}$, and district heating $HC_{h,hheat}$, is given by differentiation of the minimum expenditure per unit of aggregate heating $HEAT_h$, with the corresponding price $PHEAT_h$, at the third level of aggregation.

$$FUEL_h = aheat1_h^{sheat_h - 1} \left( \frac{PHEAT_h}{PFUEL_h} \right)^{sheat_h} \cdot HEAT_h \tag{10}$$

$$HC_{h,hel} = aheat2_h^{sheat_h - 1} \left( \frac{PHEAT_h}{PHCS_{h,hel}} \right)^{sheat_h} \cdot HEAT_h \tag{11}$$

$$HC_{h,hheat} = aheat3_h^{sheat_h - 1} \left( \frac{PHEAT_h}{PHCS_{h,hheat}} \right)^{sheat_h} \cdot HEAT_h \tag{12}$$

Where the variable $PHCS_{h,hel}$ is the price of electricity, the variable $PHCS_{h,hheat}$ is the price of district heating, $PFUEL_h$ is the fuel price, $sheat_h$ is the substitution elasticity and $aheat1_h$, $aheat2_h$, $aheat3_h$ are calibrated constants.

Households' demand of heating and other housing services (*rents*), $HEAT_h$ and $HC_{h,rents}$, respectively, are given by differentiation of the minimum expenditure per unit of housing $HOUSE_h$ with its corresponding price $PHOUSE_h$, at the second level of aggregation.

$$HEAT_h = ahouse1_h^{shouse_h - 1} \left( \frac{PHOUSE_h}{PHEAT_h} \right)^{shouse_h} \cdot HOUSE_h \tag{13}$$

$$HC_{h,rents} = ahouse2_h^{shouse_h-1} \left( \frac{PHOUSE_h}{PHCS_{h,rents}} \right)^{shouse_h} \cdot HOUSE_h \tag{14}$$

Where $shouse_h$ is the substitution elasticity, $ahouse1_h$ and $ahouse2_h$ are calibrated constants.

Households' demand of goods and services excluding transport services and housing services, $HC_{h,fno}$ is given by differentiation of the minimum expenditure function per unit of other goods and services, $OVR_h$, with the corresponding price $POVR_h$ at the second level of aggregation.

$$HC_{h,fno} = aovr_{h,fno}^{sovr_h-1} \left( \frac{POVR_h}{PHCS_{h,fno}} \right)^{sovr_h} \cdot OVR_h \tag{15}$$

The variable $PHCS_{h,fno}$ is the price including taxes for goods and services other than transport and housing services, $sovr_h$ is substitution elasticity and $aovr_{h,fno}$ is a calibrated constant.

Consumers maximize $UTOT_h$ taking market prices as given, subject to the budget constraint in equation (16):

$$\sum_{fn} PHC_{fn} \cdot HC_{h,fn} \leq PL_h \cdot LTOT_h + PC_h \cdot C_h + T_h - S_h \tag{16}$$

The left hand side of equation (16) is total expenditures of goods and services (incl. work trips), *fn*, which must be less than or equal to the sum of primary factor incomes (labour income, $PL_h \cdot LTOT$, and capital income, $PC_h \cdot C_h$), lump-sum government transfers, $T_h$, and less household's savings, $S_h$, for a household group, *h*. Transfers to a household group, $T_h$, is a given share, *transfshr*, of total government transfers, *TRANSFERS*. Savings of a household group, $S_h$, is a given share, *invshr*, of total investments, *INVS*, less the trade balance attributed to a household group as a given share, *fdeptshr*, of total exports, *EXPL*, and imports, *IMPL*, in current prices. Total investments are financed by the gross savings of the economy i.e. the sum of households' savings and the trade balance. Labour and capital income, savings, transfers and the trade balance are distributed among household groups according to their base year shares.

$$T_h = transfshr_h \cdot TRANSFERS . \tag{17}$$

$$S_h = invshr_h \cdot INVS - fdeptshr_h \cdot (EXPL - IMPL) \tag{18}$$

Total supply of skilled labour, *LSS*, and unskilled labour, *LSU*, is exogenously given and each household supplies a fixed ratio, *skshr*ₕ, of skilled labour, *LSK*ₕ, and a fix ratio, *unskshr*ₕ, of unskilled labour, *LUNSK*ₕ, according to base year data.

$$LSK_h = skshr_h \cdot LSS \tag{19}$$

$$LUNSK_h = unskshr_h \cdot LSU \tag{20}$$

The value of consumed goods and services other than work trips, $PKL_h \cdot PPK_h$, equals the value of total consumption, $\sum_{fn} PHC_{fn} \cdot HC_{h,fn}$, less the value of work trips, $PWORK_h \cdot WORK_h$, and thus:

$$PKL_h \cdot PPK_h = \sum_{FN} PHC_{FN} \cdot HC_{h,FN} - WORK_h \cdot PWORK_h \tag{21}$$

Where $PPK_h$ is the price of consumption excluding work trips and $PWORK_h$ is the price of work trips.

The categories of goods and services consumed, *FN*, by various households are transformed to composite goods, $PK_{pr}$, of private consumption by the matrix $CONS_{h,pr,fn}$.

$$PK_{pr} = \sum_h \sum_{fn=1}^{26} CONS_{h,pr,fn} \cdot HC_{h,fn} \tag{22}$$

*Public consumption*

Public goods and services are produced by a single government agent and consumed by households and firms. Total public consumption, *OKL*, is given exogenously, and the government's budget constraint is accommodated through endogenously scaling of lump sum transfers, *TRANSFERS*, to households. The government has income from taxes on labour income, *TAXL*, consumption, *TAXC*, and production, *TAXP*. The government's budget constraint is:

$$OKL = TAXL + TAXC + TAXP - TRANSFERS. \tag{23}$$

*Fixed investment and changes in stocks*

The change in capital stock is net investments accumulated at the end of the period for which the model is solved. The capital stock is assumed to grow at a uniform yearly rate, *rᵢ*, over the period and this determines net investment in each sector, $NINV_i$, for the last year of the period. Replacement is related to the capital stock by an exogenous depreciation rate, $dep_i$. The capital stock is $C_i$ and gross investment is thus given by:

$$INV_i = NINV_i + dep_i \cdot C_i \quad i = 1,...,26. \tag{24}$$

Where $NINV_i = \dfrac{C_i}{1+r_i} \cdot r_i$

Changes in stocks, $LA$, are exogenous.

*Exports*

We adopt the assumption of a small open economy for Sweden, where its products have small shares of total demand in world markets and, therefore, any quantity of exported goods must be sold at a given world market price. Hence, the export demand for Swedish products will be totally elastic. To avoid overspecialization in a model with more traded products than production factors, we assume product differentiation between exported products and products sold on the domestic market. Products intended for export are sold at world market prices, while products supplied on the domestic market are sold at domestic prices and the relative price dependent export supply function, thus introduced, is derived in section 4.3.

## 4.2 Input demands

Gross output, $Z$, is produced by means of value added, $FV$, and an energy-material aggregate, $ME$, at the highest level of aggregation. The nested structure of production is shown in Figure 3 and the top level of CES aggregation is given by equation (25).[10]

$$Z_i = \left[ \left( afv_i \cdot FV_i \right)^{(sz_i-1)/sz_i} + \left( ame_i \cdot ME_i \right)^{(sz_i-1)/sz_i} \right]^{sz_i/(sz_i-1)} \tag{25}$$

At each succeeding level, the inputs of skilled and unskilled labour, capital, various energy carriers, materials and transports are aggregated in the same manner by CES or Leontief functions.

*Demand for energy, materials and transports*

CES-functions are used to aggregate bio fuels, $IO_{bio,i}$, and coal, $IO_{coal,i}$, into solid fuels, $SFU_i$, as well as to aggregate heating oils, $IO_{oil,i}$, and gas, $IO_{gas,i}$, into liquid fuels, $LF_i$, at the lowest level of aggregation. Solid fuels and liquid fuels, in turn, are aggregated into fuels, $FU_i$, at the next level of aggregation. At the third level of aggregation, fuels, electricity, $IO_{el,i}$, and hot water, $IO_{hot,i}$, are aggregated into energy, $E_i$.

Material, $M_i$, is a Leontief aggregation of all other intermediate inputs (excl. energy inputs) including transports. The aggregate transport service is, in turn, a CES-aggregation of passenger transport, $IO_{passtp,i}$, air transport, $IO_{airtp,i}$, light truck transports, $IO_{llb,i}$, and heavy freight transport, $FRGT_i$. Heavy freight transport is a CES-aggregation of train transports, $IO_{train,i}$, sea transports, $IO_{sea,i}$, large truck transports, $IO_{slb,i}$, and medium truck transports, $IO_{mlb,i}$. The corresponding prices are, $PDS_{pr,i}$ for goods and services at the bottom levels while the prices of energy aggregates are, $PSFU_i$ (solid fuels), $PLF_i$ (liquid fuels), and $PE_i$ (total energy aggregate). The transport

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[10] The CES function is frequently used in applied general equilibrium modelling to depict the behaviour of firms and households. The CES production function and its dual cost function are used to model substitution and demand of firms' inputs. For a short introduction to the use of CES functions for modelling firms' and households' behaviour, see the Appendix C.

prices are $PFRGT_i$ (heavy freight transport) and $PTP_i$ (aggregate transports). The price of material is $PM_i$ and the price of the energy-material aggregate is $PME_i$. The substitution elasticities are *slf, ssf, sf,* and see for the energy branch of the CES-aggregation tree, while the transport elasticities are *stp* and *sfrgt*. The calibration constants of the demand equations are: *be1, be3, be4, be5, blf, bsf, be2, bf, btr,* and *bfrgt*.

**Figure 3 The input-activity specification in *EMEC***
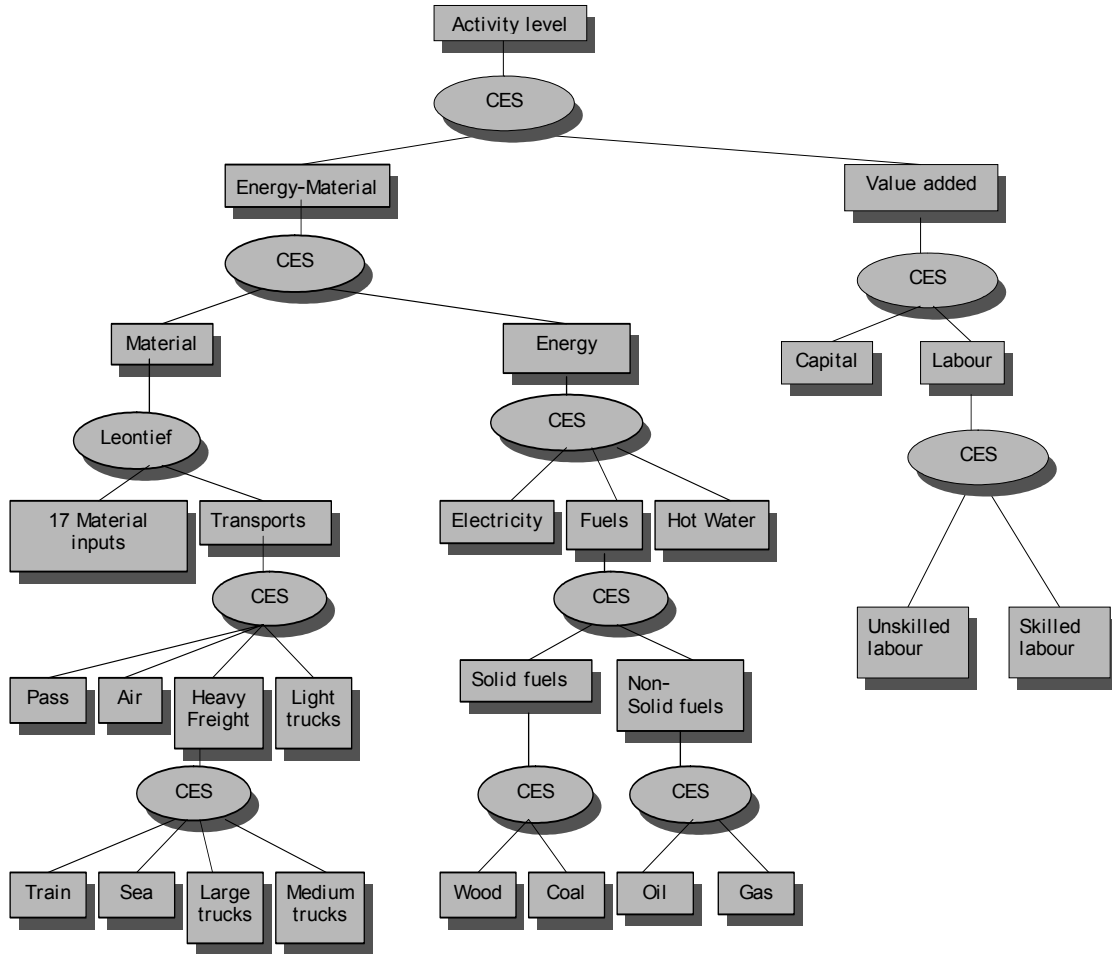


Every CES production functions have a dual cost function, and differentiation of the associated minimum unit cost functions yield demand equations of various inputs. Sectoral demand equations for oil, $IO_{oil,i}$, and gas, $IO_{gas,i}$ are arrived at by differentiating the minimum cost per unit of liquid fuels $LF_i$ at the lowest level of aggregation:

$$IO_{oil,i} = be1_i^{slf_i-1} \cdot \left( \frac{PLF_i}{PDS_{oil,i}} \right)^{slf_i} \cdot LF_i \qquad i = 1,...26. \qquad \textbf{(26)}$$

$$IO_{gas,i} = be3_i^{slf_i-1} \cdot \left( \frac{PLF_i}{PDS_{gas,i}} \right)^{slf_i} \cdot LF_i \qquad i = 1,...,26. \qquad \textbf{(27)}$$

Differentiation of the minimum cost per unit of solid fuels $SFU_i$ gives sectoral demand for bio-fuels, $IO_{bio,i}$, and coal, $IO_{coal,i}$:

$$IO_{coal,i} = be4_i^{ssf_i-1} \cdot \left( \frac{PSFU_i}{PDS_{coal,i}} \right)^{ssf_i} \cdot SFU_i \qquad i = 1,...,26. \tag{28}$$

$$IO_{bio,i} = be5_i^{ssf_i-1} \cdot \left( \frac{PSFU_i}{PDS_{bio,i}} \right)^{ssf_i} \cdot SFU_i \qquad i = 1,...,26. \tag{29}$$

Differentiation of the minimum cost per unit of fuels $FU_i$ gives sectoral demand for liquid fuels $LF_i$ and solid fuels $SFU_i$:

$$LF_i = blf_i^{sf_i-1} \cdot \left( \frac{PFU_i}{PLF_i} \right)^{sf_i} \cdot FU_i \qquad i = 1,...,26. \tag{30}$$

$$SFU_i = bsf_i^{sf_i-1} \cdot \left( \frac{PFU_i}{PSFU_i} \right)^{sf_i} \cdot FU_i \qquad i = 1,...,26. \tag{31}$$

Differentiation of the minimum cost per unit of energy $E_i$ gives sectoral demand for electricity, $IO_{el,i}$, hot water, $IO_{hot,i}$, and fuels, $FU_i$:

$$IO_{el,i} = be2_i^{see_i-1} \cdot \left( \frac{PE_i}{PDS_{el,i}} \right)^{see_i} \cdot E_i \qquad i = 1,...,26. \tag{32}$$

$$IO_{hot,i} = be6_i^{see_i-1} \cdot \left( \frac{PE_i}{PDS_{hot,i}} \right)^{see_i} \cdot E_i \qquad i = 1,...,26. \tag{33}$$

$$FU_i = bf_i^{see_i-1} \cdot \left( \frac{PE_i}{PFU_i} \right)^{see_i} \cdot E_i \qquad i = 1,...,26. \tag{34}$$

Differentiation of the minimum cost per unit of heavy freight transport $FRGT_i$ gives sectoral demand for transport services by train ($IO_{train,i}$), sea ($IO_{sea,,i}$), large truck transports ($IO_{slb,i}$) and medium truck transports ($IO_{mlb,i}$). The various heavy freight transport modes are indexed by *gtr*.

$$IO_{gtr,i} = btp_{gtr,i}^{sfrgt_i-1} \cdot \left( \frac{PFRGT_i}{PDS_{gtr,i}} \right)^{sfrgt_i} \cdot FRGT_i \qquad i = 1,...,26.; \tag{35}$$

*gtr=train, sea, mlb and slb*

Differentiation of the minimum cost per unit of aggregate transport $TP_i$ gives sectoral demand for transport services by heavy freight transport ($FRGT_i$), Passenger transports ($IO_{passtp,i}$), air transports ($IO_{airtp,i}$) and small trucks ($IO_{llb,i}$):

$$FRGT_i = bfrgt_i^{stp_i-1} \cdot \left( \frac{PTP_i}{PFRGT_i} \right)^{stp_i} \cdot TP_i \qquad i = 1,...,26. \tag{36}$$

$$IO_{trp,i} = btp_{trp,i}^{stp_i-1} \cdot \left( \frac{PTP_i}{PDS_{trp,i}} \right)^{stp_i} \cdot TP_i \qquad i = 1,...,26. \tag{37}$$

$$trp = passtp, airtp, llb$$

The intermediate demand of various material $IO_{pr,\,i}$ is a Leontief aggregate and the input coefficients, $insm_{pr,i}$ are defined as shares of total use of materials $M_i$ in equation (38). The intermediate demand for aggregate transports $TP_i$ is also a Leontief aggregate and the transport coefficients $tpinsm_{pr,i}$ are defined as shares of transports in total use of materials, in equation (39).

$$IO_{pr,i} = insm_{pr,i} \cdot M_i, \qquad \text{for all } pr \neq 4,6,15,17,19 - 21, 24 - 30. \tag{38}$$

$$TP_i = \sum_{pr=24}^{30} tpinsm_{pr,i} \cdot M_i \tag{39}$$

Differentiation of the minimum cost per unit of material-energy composite $ME_i$, with the price $PME_i$, gives sectoral demand for materials $M_i$, with the price $PM_i$, and sectoral demand of energy $E_i$ with price $PE_i$:

$$M_i = bm_i^{sme_i-1} \cdot \left( \frac{PME_i}{PM_i} \right)^{sme_i} \cdot ME_i. \quad i = 1,...,26. \tag{40}$$

$$E_i = be_i^{sme_i-1} \cdot \left( \frac{PME_i}{PE_i} \right)^{sme_i} \cdot ME_i. \quad i = 1,...,26. \tag{41}$$

Where $sme_i$ is the substitution elasticity, and $bm_i$ and $be_i$ are calibration constants.

The highest CES-aggregation level combines the energy-materials composite and the value added to output of commodities $Q_i$ with prices $PQ_i$. Factor demand of the energy-materials composite $ME_i$ is obtained by differentiation of the unit cost function of output:

$$ME_i = ame_i^{sz_i-1} \cdot \left( \frac{\sum_{pr} PQ_{pr} \cdot OUT_{i,pr}}{PME_i} \right)^{sz_i} \cdot Z_i \qquad .i = 1,...,26. \tag{42}$$

Where $sz_i$ is the substitution elasticity, $ame_i$ is a calibration constant, $OUT_{i,pr}$ is the share of good $j$ produced in sector $i$ and $Z_i$ is the activity in sector $i$.

*Demand for labour and capital*

All sectors, including public services, use skilled labour, unskilled labour and capital in a two-level CES aggregation function[11]. At the lowest level of aggregation, skilled and unskilled labour is aggregated to composite labour, which in turn is aggregated with capital to value added at the top level.

Differentiation of the minimum cost per unit of composite labour $AT_i$, with wages $WT_i$, gives sectoral demand for skilled labour $ATS_i$ and unskilled labour $ATU_i$, with the corresponding wages $WTS$ and $WTU$ :

$$ATS_i = als_i^{sat_i-1} \cdot \left[ \frac{WT_i}{WTS \cdot wsk_i} \right]^{sat_i} \cdot AT_i. \qquad i = 1,...,26 \tag{43}$$

$$ATU_i = alu_i^{sat_i-1} \cdot \left[ \frac{WT_i}{WTU \cdot wuk_i} \right]^{sat_i} \cdot AT_i. \qquad i = 1,...,26. \tag{44}$$

Where $sat_i$ is the substitution elasticity, $als_i$ and $alu_i$, are calibration constants, $wuk_i$ and $wsk_i$ are parameters explaining the wage differences between sectors.

Differentiation of the minimum cost per unit of value added $FV_i$, with price $PFV_i$, gives sectoral demand for labour $AT_i$ and capital $C_i$, with prices $PC_i$ and $WT_i$, respectively.

$$AT_i = al_i^{sfv_i-1} \cdot \left( \frac{PFV_i}{(1+tw) \cdot WT_i} \right)^{sfv_i} \cdot FV_i. \qquad i = 1,...,26. \tag{45}$$

$$C_i = ac_i^{sfv_i-1} \cdot \left( \frac{PFV_i}{(1+tc) \cdot PC_i} \right)^{sfv_i} \cdot FV_i. \qquad i = 1,...,26. \tag{46}$$

Where $sfv_i$ is the elasticity of substitution, $al_i$ and $ac_i$, are calibration constants and $tw$ and $tc$ are taxes on labour and capital, respectively.

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[11]The different kinds of labour are defined in Appendix A.

At the top level of CES-aggregation, the energy-materials composite and value added are combined to gross output. Factor demand of value added is obtained by differentiating the unit cost function of output:

$$FV_i = afv_i^{sz_i-1} \cdot \left( \frac{\sum\limits_{pr} PQ_j \cdot OUT_{i,pr}}{PFV_i} \right)^{sz_i} \cdot Z_i. \qquad i = 1,...,26. \qquad \textbf{(47)}$$

## 4.3 Total domestic demand and output

*Domestic demand in basic values*

All components of demand are measured at constant prices in basic values. Total domestic demand in basic values, $DZ_i$, for each commodity, except for commodity 32 (Services incl. trade), is:

$$DZ_{pr} = \sum_i IO_{pr,i} + PK_{pr} + inv_{pr} \cdot INVS + la_{pr} \cdot LA, \quad pr = 1,...,31, 33. \qquad \textbf{(48)}$$

To obtain total domestic demand for, $pr=32$, we must add also the trade margins to equation (48), where the term $\sum\limits_i IO_{pr,i}$ is intermediate use, $PK_{pr}$ is private consumption, $inv_{pr} \cdot INVS$ is investment, and $la_{pr} \cdot LA$ is the change of stocks.

*Domestic demand of output and imports*

Domestic consumers, including firms and producers of public services, are assumed to treat domestic goods as imperfect substitutes for imported goods classified in the same category. A CES-function, describes this trade-off between demand of produced goods $QH_{pr}$, and imported goods, $IMP_{pr}$, in creation of the composite good, $DZ_{pr}$ supplied at the domestic market. For the public sector $DZ_{Gov}$ is public consumption and equals $QH_{Gov}$.

$$DZ_{pr} = \left[ \left( aqi_{pr} \cdot QH_{pr} \right)^{(sdz_{pr}-1)/sdz_{pr}} + \left( am_{pr} \cdot IMP_{pr} \right)^{(sdz_{pr}-1)/sdz_{pr}} \right]^{sdz_{pr}/(sdz_{pr}-1)}$$
$$pr = 1,...,33. \qquad \textbf{(49)}$$

Where $sdz_{pr}$ is the substitution elasticity, and $am_{pr}$ and $aqi_{pr}$ are calibration constants.

The CES-function in (49), together with the constraint of no profits in creation of the composite good, gives demand for imports, $IMP_{pr}$, at prices $PIMP_{pr}$ and $PDZ_{pr}$.

$$IMP_{pr} = am_{pr}^{sdz_{pr}-1} \cdot \left( \frac{PDZ_{pr}}{PIMP_{pr}} \right)^{sdz_{prr}} \cdot DZ_{pr}. \qquad pr = 1,...,33. \tag{50}$$

Where $sdz_{pr}$ is the substitution elasticity and $am_{pr}$ is a calibration constant.

*Supply of output for domestic use and for export*

The firm decides on the optimal mix of output for the domestic market, $QH_{pr}$, sold at domestic prices, $PQH_{pr}$, and output for the export market, $EXP_{pr}$, sold at world market prices $PW_{pr}$. The trade off between domestic supply and export of produced goods, $Q_{pr}$, is described by a CET-function.

$$Q_{pr} = \left[ (aq_{pr} \cdot QH_{pr})^{(se_{pr}-1)/se_{pr}} + (ae_{pr} \cdot EXP_{pr})^{(se_{pr}-1)/se_{pr}} \right]^{se_{pr}/(se_{pr}-1)} \tag{51}$$
$$pr = 1,...,33$$

The export supply function is:

$$EXP_{pr} = ae_{pr}^{se_{pr}-1} \cdot WM_{pr} \cdot \left[ \frac{PQ_{pr}}{PW_{pr}} \right]^{se_{pr}} \cdot Q_{pr} \qquad pr = 1,...,33. \tag{52}$$

Where $se_{pr}$ is a substitution elasticity, $WM_{pr}$ is an index of export market size and the calibration constants are $ae_{pr}$ and $aq_{pr}$.

Output of the public sector $Q_{Gov}$ is set equal to the exogenously given public consumption $OKL$ or equally $DZ_{Gov}$.

## 4.4        Emissions of pollutants

Carbon dioxide ($CO_2$), sulphur dioxide ($SO_2$), nitrogen oxides ($NO_x$), nitrous oxide ($N_2O$), carbon monoxide ($CO$), methane ($CH_4$) and particulate matter (PM10, PM25) are emitted by production in the use of materials and fuel inputs and by households in the consumption of fuels.

The model evaluates the emissions as a function of the energy use and the material input for industries and the energy use for households. Total emissions of $CO_2$, $SO_2$, $NO_x$, $N_2O$, $CO$, PM10, PM25 and $CH_4$ in the use of energy and materials in production are given by:

$$EM_{po} = \sum_{pr} \sum_{i} emcoef_{pr,po,i} \cdot IO_{pr,i} + \sum_{i} emcoefm_{po,i} \cdot M_i \tag{53}$$

Where $emcoef_{e,po,i}$ are emission coefficients in the use of energy carriers, $pr = 4, 6, 15, 16, 18, 19$ and $20$, and $emcoefm_{po,i}$ are emission coefficients in the use of mate-

rials $M_i$ for emissions $po$ = CO₂, SO₂, NOₓ, N2O, CO, PM10, PM25 and CH4 in sector $i$.

Total emissions in the use of energy by households are given by:

$$EMH_{po} = \sum_h \sum_{fn} emhcoef_{fn,po} \cdot HC_{h,fn} \tag{54}$$

Where $emhcoef_{en,po}$ are the coefficients for emission of CO₂, SO₂, NOₓ, N₂O, CO, PM10, PM25 and CH₄ in private consumption of the energy commodities (household goods $fn$=17, 18, 19, 20, 21, 22, 23, 24).

## 4.5    Price setting

We assume constant returns to scale and mobile factor inputs between sectors. Domestic supply is then completely elastic for each good. Prices of goods are determined only by factor prices given by equilibrium in factor markets. The supply of imports is also completely elastic, and the prices of imports and exports are exogenous world market prices.

$WTS$ and $WTU$ are equilibrium wages on the two labour markets. The two types of labour are assumed perfectly mobile between sectors. The wage levels actually observed for each category of labour, however, differ among sectors. These initial distributions of wages, $wsk$ and $wuk$, are kept unchanged in simulations. For each sector, the wage cost per hour of aggregated labour $WT_i$ is given by:

$$WT_i \cdot AT_i = WTS \cdot wsk_i \cdot ATS_i + WTU \cdot wuk_i \cdot ATU_i \qquad i=1,...,26 \tag{55}$$

The price of capital $PC_i$ is defined as the cost of using one unit of real capital:

$$PC_i = [r_i \cdot R + dep_i] \cdot PINV, \qquad i=1,...,26. \tag{56}$$

Where $R$ is the average level of the real rate of return before taxes. The distribution of return to capital among sectors, $r_i$, as well as the distributions of wages are exogenous and can be observed for the calibration year.[12]

CES-aggregation of composite labour and capital to value added together with the assumption of perfect competition give the value added price $PFV_i$ in terms of the factor prices $WT_i$ and $PC_i$ at optimal factor allocation with the factor taxes $tw$ and $tc$:

$$PFV_i \cdot FV_i = (1+tw) \cdot WT_i \cdot AT_i + (1+tc) \cdot PC \cdot C_i \quad i=1,...,26 \tag{57}$$

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[12]This formulation of the model could be questioned as well as the corresponding assumption about wage differentials for homogenous labour. There may be several explanations for the observed sectoral differences in real rates of return and the most obvious is that no adjustment has been made for taxes. Another explanation is differences in risk. It is also important that the calibration year is unlikely to exhibit a long run equilibrium position for all sectors. For labour one might also add that under the two categories of labour there is a structure of skill that may differ between sectors.

$PDZ_{pr}$ is the price of the composite good $DZ_{pr}$ on domestic markets when it leaves the combined plant-import harbour, and it is calculated from the import price $PIMP_{pr}$ and the price of domestic commodities in basic values $PQH_{pr}$. Trade margins and commodity taxes are added to this price before the good reaches the ultimate consumer. It is assumed that trade margins are added in equal proportion to all uses of the composite good except for exports. This is obviously a major simplification.[13] Firstly, some of the trade margins are levied on exports, which can be seen from IO-data. Also, trade margins are much larger for private consumption (retail plus wholesale) than for intermediate goods (wholesale only). A more detailed account of trade margins will, however, greatly complicate the equations of the model.

$$PDZ_{pr} \cdot DZ_{pr} = PIMP_{pr} \cdot IMP_{pr} + PQH_{pr} \cdot QH_{pr} \qquad pr = 1,...33. \qquad (58)$$

It is assumed that the price of trade margins follows the domestic price of the commodity 32 Services, $PDZ_{32}$, rather than the price of the commodity itself. This seems a reasonable assumption in the medium and long run. Domestic prices $PD_{pr}$ including trade margins are:

$$PD_{pr} = \left(PDZ_{pr} + hm_{pr} \cdot PDZ_{32}\right)/\left(1 + hmk_{pr}\right), \quad pr = 1,...,33. \qquad (59)$$

Trade margins can be changed exogenously by the parameter $hm_{pr}$. The parameter values of $hmk_{pr}$ are calibration constants.

Commodity taxes levied on the inputs of production include VAT, other indirect commodity taxes and subsidies, energy tax, carbon tax, sulphur tax and a kilometre tax for large truck transports. The tax on energy, environmental taxes and the kilometre tax are based on quantities, while the net of VAT, other indirect commodity taxes and subsidies are ad valorem.

The prices of energy and material inputs in production including taxes are given by:

$$PDS_{pr,i} = PD_{pr} \cdot \left(1 + itp_{pr}\right) + itpe_{i.pr} + itpSO2_{i,pr} + itpCO2_{i,pr} + itpKM_{i,pr} \qquad (60)$$

for $i = 1,...,25 \quad and \quad pr = 1,....33$,

Where $itp_{pr}$ is the ad volorem net tax on inputs of good $pr$ and $itpe_{i,pr}$, $itpSO2_{i,pr}$, $itpCO2_{i,pr}$ and $itpKM_{i,pr}$ are energy tax, sulphur tax, carbon tax or permit price and kilometre tax for large truck transports, respectively, on good $pr$ in sector $i$. The energy tax and the environmental taxes are specific to various industries so as to allow for tax exemptions. Permit trading is analysed with $itpCO2_{i,pr}$ equal to the permit price for trading sectors.

The variable $PDS_{pr,i}$ are equilibrium prices, including taxes, on the goods markets for all commodities and must be aggregated to have the prices $PE_i$, $PFU_i$,

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[13]Trade margins may make up for a substantial part of the ultimate price for some goods.

$PLF_i$ and $PSFU_i$ of the corresponding energy aggregates $E$ (total energy), $FU$ (fuels), $LF$ (liquid fuels) and $SFU$ (solid fuels). The CES-aggregation of $PE_i$ is:

$$PE_i = \left[ \left( \frac{PFU_i}{bf_i} \right)^{1-see_i} + \left( \frac{PDS_{el,i}}{be2_i} \right)^{1-see_i} + \left( \frac{PDS_{hot,i}}{be6_i} \right)^{1-see_i} \right]^{\frac{1}{1-see_i}} \qquad i=1,...,26 \qquad (61)$$

Where the CES-aggregation of the price of fuels $PFU_i$ is

$$PFU_i = \left[ \left( \frac{PLF_i}{blf_i} \right)^{1-sf_i} + \left( \frac{PSFU_i}{bsf_i} \right)^{1-sf_i} \right]^{\frac{1}{1-sf_i}} \qquad i=1,...,26 \qquad (62)$$

and the CES-aggregation of the prices of liquid fuels $PLF_i$ and solid fuels, $PSFU_i$ are:

$$PLF_i = \left[ \left( \frac{PDS_{oil,i}}{be1_i} \right)^{1-slf_i} + \left( \frac{PDS_{gas,i}}{be3_i} \right)^{1-slf_i} \right]^{\frac{1}{1-slf_i}} \qquad i=1,...,26 \qquad (63)$$

$$PSFU_i = \left[ \left( \frac{PDS_{coal,i}}{be4_i} \right)^{1-ssf_i} + \left( \frac{PDS_{bio,i}}{be5_i} \right)^{1-ssf_i} \right]^{\frac{1}{1-ssf_i}} \qquad i=1,...,26 \qquad (64)$$

Also, the prices $PFRGT$ and $PTP$ of heavy freight transport ($FRGT$) and aggregate transports) ($TP$), respectively, are derived by aggregating the prices $PDS_{pr,i}$.

$$PTP_i = \left[ \sum_{trp} \left( \frac{PDS_{trp,i}}{btp_{trp,i}} \right)^{1-stp_i} + \left( \frac{PFRGT_i}{bfrgt_i} \right)^{1-stp_i} \right]^{1/1-stp_i} \qquad \begin{array}{l} i=1,...,26 \\ trp=passtp,airtp,llb \end{array} \qquad (65)$$

Where the price of heavy freight transport $PFRGT_i$ is:

$$PFRGT_i = \left[ \sum_{grt} \left( \frac{PDS_{grt,i}}{btp_{gtr,i}} \right)^{1-sfrgt_i} \right]^{1/1-sfrgt_i} \qquad \begin{array}{l} i=1,...,26 \\ gtr=train,sea,\ mlb,slb \end{array} \qquad (66)$$

The price of materials is given by the following Leontief aggregation:

$$PM_i = \sum_{pr \neq 4,6,15,17,19-21,24-31} PDS_{pr,i} \cdot insm_{pr,i} \cdot \qquad i=1,...,26$$

The CES-aggregation of composite energy and materials to an energy-material aggregate, together with the assumption of perfect competition yield the energy-material

price $PME_i$ in terms of the prices $PM_i$ and $PE_i$ at optimal allocation of energy carriers.

$$PME_i = \left[\left(\frac{PM_i}{bm_i}\right)^{1-sme_i} + \left(\frac{PE_i}{be_i}\right)^{1-sme_i}\right]^{\frac{1}{1-sme_i}} \qquad i = 1,...,26. \qquad (67)$$

Commodity prices $PQ_j$ are computed from the relation of no profits in production, i.e. total revenue equals total costs for all firms at activity $Z_i$:

$$\sum_j PQ_j \cdot OUT_{ij} \cdot Z_i = PFV_i \cdot FV_i + PME_i \cdot ME_i \qquad i = 1,...,26. \qquad (68)$$

The tax base for VAT is assumed to consist of mainly private consumption, although other components of demand can be taxed. Private consumption is also subject to energy tax, $itce_{fn}$, carbon tax, $itcCO2_{fn}$, sulphur tax, $itcSO2_{fn}$ and other indirect taxes and subsidies, $itci_{fn}$. Prices of consumer categories, including indirect commodity taxes, $PHCS_{h,fn}$, are given by:

$$PHCS_{h,fn} = \left(1 + itcmoms_{fn} + itci_{fn}\right) \cdot PHC_{h,fn} + itce_{fn} + itcSO2_{fn} + itcCO2_{fn} + itcNOx_{fn}$$
$$i = 1,...,26$$
$$(69)$$

Where:

$$PHC_{h,fn} = \sum_{pr} PD_{pr} \cdot CONS_{h,pr,fn}, \qquad i = 1,...,26 \qquad (70)$$

For the aggregate consumption, excluding work trips, of a household, $PKL_h$ the price, $PPK_h$, is given by:

$$PPK_h = \left[\left(\frac{POVR_h}{ak3_h}\right)^{1-spk_h} + \left(\frac{PHOUSE_h}{ak1_h}\right)^{1-spk_h} + \left(\frac{PFRITRANS_h}{ak2_h}\right)^{1-spk_h}\right]^{\frac{1}{1-spk_h}} \qquad (71)$$

Where the prices $POVR_h$, $PHOUSE_h$ and $PFRITRANS_h$ also are CES-aggregates as shown in appendix B.

For the aggregate of a household's work trips, $WORK_h$, the price, $PWORK_h$, is given by:

$$PWORK_h = \left[ \sum_{trw} \left( \frac{PHCS_{trw,h}}{atrw_{trw,h}} \right)^{1-swork_h} \right]^{1/1-swork_h} \tag{72}$$

The price of labour (the unit net labour income) for a household, $PL_h$, is given by:

$$PL_h = sskshr_h \cdot WTS + unsskshr_h \cdot WTU \tag{73}$$

Investments in all sectors are assumed to consist of composite good aggregated with the shares $inv_{pr}$ making the aggregate price $PINV$ of the common investment good equal to:

$$PINV = \sum_{pr=1}^{32} inv_{pr} \cdot PD_{pr} \tag{74}$$

Finally the price of investments in stocks is:

$$PLA = \sum_{pr=1}^{32} la_{pr} \cdot PD_{pr} \tag{75}$$

## 4.6 Market clearing, closure rules, numeraire and emission constraints

Factor supply is either exogenous, making factor prices endogenous, or completely elastic with exogenous factor prices. The latter alternative may seem more relevant for capital and is chosen for the current version of *EMEC*. Some interesting results could be obtained by applying this approach also to skilled labour, remembering that the time perspective may be long enough to treat the economy as open, not only in goods- and capital-markets, but also in segments of the labour market. Nevertheless, the current version of the model is run with exogenous labour supply.

The equilibrium conditions simply state that demand equals supply of production factors *LSK*, *LUNSK* and *CS*:

$$\sum_h LSK_h = \sum_{i=1}^{26} ATS_i. \tag{76}$$

$$\sum_h LUNSK_h = \sum_{i=1}^{26} ATU_i \tag{77}$$

$$CS = \sum_{i=1}^{26} C_i \tag{78}$$

The model must include a relation for the current account to link the income and expenditure sides of the economy and to determine overall savings. To be more specific, consumer expenditures in $UTOT_h$ must be determined. This can be accomplished by letting either household savings or the current account (trade balance) or the gross-savings ratio to be exogenous. In the last case, disposable incomes must be computed to determine consumption expenditures consistent with the exogenous household savings. In the present version of EMEC, we maximize the level of private consumption expenditures, consistent with the exogenous current account ratio. Finally, the exchange rate is the numeraire and the foreign price level is set exogenously.

We can also run the model with restrictions on the emission levels, $EBAR_{po}$:

$$EMTOTAL_{po} \leq EBAR_{po}, \qquad po = CO_2, SO_2, NO_x, N_2O, PM10, PM25, CO, CH_4. \qquad (79)$$

# 5 Calibration and Parameter Values

Most CGE-models are calibrated for a specific year using an elaborated database. Prices of the calibration year are chosen as the base for price indices. The conventional choice of base year is the latest year for which a set of complete National Accounts exists. The calibration procedure runs along standard lines. We assume static equilibrium with perfect competition and solve for unknown constants of the utility function and the production functions. The model solution of the calibration year reproduces observed prices and quantities. Substitution elasticities in the CES- and CET-aggregators must be specified before calibration. The figures given in Table 1 are used in the present version of the model.

The art of finding elasticity values for all the CES functions of a large CGE model like EMEC seldom includes an econometric estimation of the models equations due to the large amount of data needed and the huge effort of estimating all of the equations. The procedure adopted is instead that of picking the elasticity values by surveying econometric studies concentrating on the estimation of a few of all the relations captured by a CGE model. The elasticity values of substitution are generally "guesstimated" as concluded by Bergman (2005). The elasticity values collected from such partial studies might not interact very well within a general equilibrium framework, so there must always be some kind of judgement approach considering the accuracy of model results, when setting the elasticity values of a CGE model.

The elasticity values of substitution for foreign-domestic goods, energy-material input, input of various energy carriers and input of transport modes was collected by surveying a number of studies, van Leeuwen et. al.(1995), Bovenberg, and Gouldner (1996), Kemfert and Welsch (1997), Kremers et.al. (2002), Steininger (2002), Litman (2005), Koschel, H., (2000), but also a significant influence of judgement determines these elasticity values. The elasticity values of the consumption function are taken from Nilsson ( 2004), se Table 2.

Estimates of the export/domestic transformation elasticity are rare but Dixon et-al. (1992) has suggested a method of calculating these values from input-output data of the base period. The value of the transformation elasticity is calculated as the industry's share of total revenue accounted for by exports. The method of Dixon et-al. (1992) was applied to the input-output data of 2002 to calculate values of the transformation elasticity, **se**, shown in table 3.

**Table 1 Substitution elasticities in production sectors**

| Production sector | sat | Sfv | Sz | sme | see | sf | slf | ssf | stp | sfrgt |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Agriculture | 1,1 | 0,5 | 0,3 | 0,5 | 0,6 | 0,7 | 0,8 | 0,9 | 0,1 | 0,2 |
| 2. Fishery | 1,1 | 0,3 | 0,2 | 0,3 | 0,4 | 0,7 | 0,7 | 0,9 | 0,1 | 0,2 |
| 3. Forestry | 1,1 | 0,5 | 0,3 | 0,4 | 0,5 | 0,7 | 0,8 | 0,9 | 0,1 | 0,2 |
| 4. Mining | 1,1 | 0,8 | 0,3 | 0,4 | 0,5 | 0,6 | 0,8 | 0,9 | 0,1 | 0,2 |
| 5. Other industries | 1,1 | 0,8 | 0,3 | 0,4 | 0,6 | 1,2 | 1,3 | 1,4 | 0,1 | 0,2 |
| 6. Mineral products | 1,1 | 0,8 | 0,7 | 0,9 | 0,6 | 1,2 | 1,3 | 1,4 | 0,1 | 0,5 |
| 7. Pulp and paper mills | 1,1 | 0,8 | 0,7 | 0,9 | 1,1 | 1,2 | 1,3 | 1,4 | 0,1 | 0,3 |
| 8. Drug industries | 1,1 | 0,8 | 0,3 | 0,4 | 0,6 | 1,2 | 1,3 | 1,3 | 0,1 | 0,2 |
| 9. Chemical industries | 1,1 | 0,8 | 0,7 | 0,8 | 0,9 | 1,2 | 1,3 | 1,3 | 0,1 | 0,3 |
| 10. Iron & Steel industries | 1,1 | 0,8 | 0,4 | 0,5 | 0,6 | 1,2 | 1,3 | 1,3 | 0,1 | 0,5 |
| 11. Non-iron metal ind. | 1,1 | 0,8 | 0,3 | 0,4 | 0,5 | 0,7 | 0,9 | 0,9 | 0,1 | 0,5 |
| 12. Engineering | 1,1 | 0,8 | 0,6 | 0,7 | 0,8 | 1,2 | 1,3 | 1,3 | 0,1 | 0,4 |
| 13. Petroleum refineries | 1,1 | 0,2 | 0,1 | 0,3 | 0,4 | 0,8 | 0,9 | 0,9 | 0,1 | 0,2 |
| 14. Electricity supply | 1,1 | 0,3 | 0,1 | 0,1 | 0,3 | 1,1 | 1,5 | 1,5 | 0,1 | 0,2 |
| 15. Hot water supply | 1,1 | 0,3 | 0,1 | 0,1 | 0,3 | 1,1 | 1,5 | 1,5 | 0,1 | 0,2 |
| 16. Gas distribution | 1,1 | 0,3 | 0,1 | 0,1 | 0,2 | 0,2 | 0,2 | 0,2 | 0,1 | 0,2 |
| 17. Water and sewage | 1,1 | 0,3 | 0,2 | 0,3 | 0,4 | 0,7 | 0,7 | 0,7 | 0,1 | 0,2 |
| 18. Construction | 1,1 | 0,3 | 0,2 | 0,3 | 0,7 | 0,8 | 0,9 | 0,9 | 0,1 | 0,2 |
| 19. Rail road transports | 1,1 | 0,2 | 0,2 | 0,3 | 0,3 | 0,2 | 0,2 | 0,2 | 0,1 | 0,2 |
| 20 Road goods transports | 1,1 | 0,2 | 0,2 | 0,3 | 0,3 | 0,2 | 0,2 | 0,2 | 0,1 | 0,2 |
| 21. Road passenger transports | 1,1 | 0,2 | 0,2 | 0,3 | 0,3 | 0,2 | 0,2 | 0,2 | 0,1 | 0,2 |
| 22. Sea transports | 1,1 | 0,2 | 0,2 | 0,2 | 0,2 | 0,3 | 0,3 | 0,3 | 0,1 | 0,2 |
| 23. Air transports | 1,1 | 0,2 | 0,2 | 0,3 | 0,3 | 0,2 | 0,2 | 0,2 | 0,1 | 0,2 |
| 24. Other transports | 1,1 | 0,8 | 0,6 | 0,7 | 0,8 | 0,8 | 0,8 | 0,8 | 0,1 | 0,2 |
| 25. Services | 1,1 | 0,8 | 0,7 | 0,9 | 1,1 | 1,2 | 1,3 | 1,4 | 0,1 | 0,2 |
| 26. Real estate | 1,1 | 0,6 | 0,5 | 0,8 | 1,2 | 1,2 | 1,5 | 1,6 | 0,1 | 0,2 |
| 27. Public services | 1,1 | 0,7 | 0,1 | 0,7 | 1,1 | 1,2 | 1,3 | 1,4 | 0,1 | 0,2 |

## Table 2 Substitution elasticities in consumption

| Label of parameter in the consumption function | Elasticity value |
|---|---|
| swork | 0.5 |
| spkl | 0.5 |
| sfritrans | 0.9 |
| sshort | 0.8 |
| sholi | 0.7 |
| sfuel | 0.5 |
| sheat | 0.6 |
| shouse | 0.3 |
| sovr | 0.9 |

**Table 3  Elasticities of commodities in foreign trade**

| Commodity | sdz | se |
|---|---|---|
| 1. Agricultural products | 0.4 | -1.1 |
| 2. Fish | 1.4 | -6.0 |
| 3. Timber | 0.4 | -1.0 |
| 4. Bio fuels | 0.4 | -1.0 |
| 5. Metal ores and stone | 0.6 | -1.4 |
| 6. Coal | 0.3 | 0.0 |
| 7. Products n.e.c. | 0.7 | -1.5 |
| 8. Mineral products | 0.7 | -1.5 |
| 9. Pulp and paper | 1.1 | -1.9 |
| 10. Pharmacy products | 1.8 | -6.3 |
| 11. Other chemical products | 1.6 | -3.0 |
| 12. Iron and steel | 1.1 | -3.0 |
| 13. Other metals | 1.1 | -2.5 |
| 14. Engineering products | 0.7 | -2.7 |
| 15. Fuels | 1.1 | -2.1 |
| 16. Motor fuels | 1.3 | -2.4 |
| 17. Other petroleum products | 1.3 | -2.6 |
| 18 Crude petroleum | 0.2 | -1.0 |
| 19. Electricity | 0.5 | -1.0 |
| 20. Steam and hot water | 0.5 | -1.0 |
| 21. Gas | 0.5 | -1.0 |
| 22. Fresh water | 0.1 | -1.0 |
| 23. Building | 0.3 | -1.0 |
| 24. Rail transports | 0.5 | -1.1 |
| 25. Passenger transports | 0.5 | -1.0 |
| 26. Small Truck transports | 0.5 | -1.0 |
| 27. Middle Truck transports | 0.5 | -1.0 |
| 28. Large Truck transports | 0.6 | -1.3 |
| 29. Sea transports | 1.1 | -4.0 |
| 30. Air transports | 0.7 | -1.5 |
| 31. Other transports | 0.5 | -1.1 |
| 32. Business and private services | 0.6 | -1.2 |
| 33. Dwellings | 0.3 | -1.0 |

# 6  Conclusions: future developments

The present paper presents a new version of the Swedish computable general equilibrium model EMEC, which has been developed at the National Institute of Economic Research for analysis of the economy's environmental interactions in a medium term perspective. The model produces results for endogenous variables at a disaggregated level and consistent with economic theory, data and the assumptions underlying the exogenous variables.

This new version of EMEC has a detailed description of transport demand for the industry sector as well as for the household sector. Also, firms and households may substitute a relative dearer transport mode for other transport modes. The new version of the model, thus, is better suited for analysing the impact of road user charges, actually discussed in Sweden, as well as other price inducing policy measures affecting transport services.

Policy measures aimed at reducing polluting emissions might have welfare effects, which differ among regions and among income groups. Also, a policy measure might affect emission levels somewhat different for various regions and income groups due to different patterns of consumption and personal transportation. Such distributional aspects of e.g. climate policy can now be assessed as households are subdivided into two income groups and three regional groups in the new version of EMEC.

The new version has a more detailed representation of the production sectors trading with emission permits within the EU trading system of $CO_2$ emissions. Also, electricity supply and hot water supply is separated into different subsectors of industry.

All these improvements and extensions of the model structure result in 26 subsectors of industry, 6 household groups, 33 commodities, 26 consumption goods, 18 production factors, which are substitutes, 6 energy carriers and 8 modes of transportation and 8 emissions to the air. The EMEC model is an ongoing project at the National Institute of Economic Research and future development includes the modelling of an endogenous labour supply.

# Appendix A: Definitions and Variables

## A.1  Definitions and data sources

*Sector and commodity classifications*

*EMEC* distinguishes 27 producing sectors - 26 business sectors and a public sector-
and 33 produced and/or imported commodities. Table A1 gives the definitions of
sectors and Table A2 presents the definitions of commodities in the database. All
variables related to production are taken from the System of National Accounts
(SNA) but the commodities bio fuels, coal and crude petroleum are not disaggregated
in the SNA, but by the authors. The transports by various types of trucks (Commodi-
ties 25, 26 and 27) are not distinguished in the SNA, but by the authors in using the
"Körsträckedatabas" for 2002. The supply table, the use table, capital stocks and
investments by sector are from 2002. All the SNA data were aggregated by the au-
thors to fit the model's definitions of variables.

*Classification of private consumption*

*EMEC* distinguishes 26 commodities in private consumption and Table A3 gives the
exact definitions of the commodities. All variables related to consumption are taken
from the SNA, but the RES database is used by the authors to subdivide transport
modes by purposes. The RES database is from 2001.

 Households are subdivided into six household groups by disposal income level
and by residence according to the Household expenditure survey (HEK) of 1999-
2001. The household groups are defined in Table A4.

*Labour categories*

The distributions of 9 different kinds of labour and their labour income across sec-
tors are taken from the Household expenditure survey (HEK) 2003. The labour cate-
gories are defined according to the level of education. Skilled labour includes those
with a post high school education and the remaining groups are classified as unskilled
labour. Employment and income figures are adjusted to SNA levels by simple scaling.

*Emission data*

*EMEC* distinguishes 8 pollutants emitted by the combustion of 5 energy carriers in
various production sectors and by households. Carbon dioxide ($CO_2$), sulphur diox-
ide ($SO_2$), nitrogen oxides ($NO_x$), nitrous oxide ($N_2O$), carbon monoxide ($CO$),
methane ($CH_4$) and particulate matter (PM10, PM25). Table A5 gives the definitions
of energy carriers. All variables related to pollutants and energy carriers are taken
from the System of Environmental Accounts (SEA). All the SEA data were aggre-
gated by the authors to fit the model's definitions of variables.

*Factor prices*

Wages are defined as labour cost per hour. Wages for aggregate labour are taken from
SNA. Capital cost, $PC$, is defined per unit of physical capital valued at 2002 prices

and is computed from SNA as gross operating surplus $OS$ divided by the capital stock $C$:

$$PC = \frac{OS}{C}, \text{ where } OS = PFV \cdot FV - WT \cdot AT$$

$PFV \cdot FV$ is value added in current prices and $WT \cdot AT$ is the cost of labour.

Dividing $PC$ by the price of investment goods, $PI$, and subtracting the depreciation rate, $\delta$, yields the net real rate of return on physical capital (before taxes):

$$R = \frac{PC}{PI} - \delta$$

Here, $R$ is the variable used in equilibrating the market for fixed capital in the model. From the definitions above the operating surplus can be expressed as:

$$OS = PFV \cdot FV - WT \cdot AT = PC \cdot C = (R + \delta) \cdot PI \cdot C$$

**Table A1 Definitions of private production sectors**

| Production sector in EMEC | NACE Rev.1* | Sector label in the Swedish National Accounts |
|---|---|---|
| 1. Agriculture | 01 | Agriculture and hunting |
| 2. Fishery | 05 | Fishing |
| 3. Forestry | 02 | Forestry and logging |
| 4. Mining | 13 | Metal ore mining |
| | 14 | Other mining and quarrying |
| 5. Other industries | 15,16 | Manufacture of food, beverage and tobacco |
| | 17-19 | Textile industries |
| | 20 | Manufacture of wood and wood products |
| 6. Mineral products | 26 | Manufacture of non-metallic mineral products |
| 7. Pulp and paper mills | 21 | Manufacture of pulp, paper and paper products |
| | 22 | Printing and publishing |
| 8. Drug industries | 244 | Manufacture of pharmaceuticals products |
| | 245 | Manufacture of soap and detergents |
| 9. Other chemical industries | 24 excl 244,245 | Manufacture of chemicals and chemical products |
| | 25 | Manufacture of rubber and plastic products |
| 10. Iron & steel industries | 271-273 | Iron steel basic industries |
| 11. Non-iron metal industries | 274-275 | Non-ferrous metal basic industries |
| 12. Engineering | 28 | Manufacture of metal products |
| | 29 | Manufacture of mechanical machinery |
| | 30,31 | Manufacture of electrical machinery and computers |
| | 32 | Manufacture of communication equipment |
| | 33 | Manufacture of measuring equipment, etc. |
| | 34,35 | Manufacture of transport equipment |
| | 36,37 | Other manufacturing industries |
| 13. Petroleum refineries | 23 | Petroleum refining |
| 14. Electricity supply | 401 | Electricity |
| 15. Hot water supply | 403 | Steam and hot water supply |
| 16. Gas distribution | 402 | Gas manufacture and distribution |
| 17. Water and sewage | 41 | Water supply and sewage disposal |
| 18. Construction | 45 | Construction |
| 19. Rail road transports | 601 | Railway road transports |
| 20 Road goods transports | 6024 | Road goods transports |
| 21. Road passenger transports | 6021-6023 | Road passenger transports |
| 22. Sea transports | 61 | Water transports |
| 23. Air transports | 62 | Air transports |
| 24. Other transports | 63 | Other transport activities |
| | 64 | Communications |
| 25. Services | 50-52 | Wholesale and retail trade |
| | 55 | Restaurants and hotels |
| | 65 | Financial institutions |
| | 66 | Insurance |
| | 71-74 | Business services |
| | 75,80-85,90-95 | Other private services |
| 26. Real estate | 70 | Letting of dwellings and other real estate |

*Nomenclature Général des Activités Economiques dans les Communautés Européennes. The statistical classification of economic activities in the European Community amended in March 1993.

Table A2 Definition of commodities

| Commodity in EMEC | CPA code* | Commodity label in the Swedish National Accounts |
|---|---|---|
| 1. Agricultural products | 01 | Products of agriculture and hunting |
| 2. Fish | 05 | Fish and fishing products |
| 3. Timber | 02 | Products of forestry and logging |
| 4. Bio fuels | 02 pt | Wastes from logging |
| 5. Metal ores | 13 | Metal ores |
| | 14 | Other mining and quarrying products |
| 6. Coal | 10 | Coal |
| 7. Products n.e.c. | 15,16 | Food products, beverages and tobacco products |
| | 17-19 | Textiles and textile products |
| | 20 | Wood and wood products |
| 8. Mineral products | 26 | Non-metallic mineral products |
| 9. Pulp and paper | 21 | Pulp,paper and paper products |
| | 22 | Printed matter |
| 10. Pharmacy products | 244 | Pharmaceuticals and medical chemicals |
| | 245 | Soap,detergents and cosmetics |
| 11 Other chemical products | 24 excl 244,245 | Chemicals and chemical products |
| | 25 | Rubber and plastic products |
| 12. Iron and steel | 271-273 | Basic iron and steel , tubes and wires |
| 13. Other metals | 274,275 | Basic non-ferrous metals |
| 14. Engineering products | 28 | Metal products |
| | 29 | Mechanical machines |
| | 30,31 | Electric machines and computers |
| | 32 | Communication equipment |
| | 33 | Measuring equipment |
| | 34,35 | Transport equipment |
| | 36,37 | Other manufactured products |
| 15. Fuels | 23200 pt | Heating oils |
| 16. Motor fuels | 23200 pt | Motor gasoline,diesel and jet fuels |
| 17. Other petroleum products | 23200 pt | Other refined petroleum products |
| 18. Crude petroleum | 11 | Crude petroleum |
| 19. Electricity | 401 | Electricity |
| 20. Steam and hot water | 403 | Steam and hot water |
| 21. Gas | 402 | Manufactured and distributed gas |
| 22. Fresh water | 41 | Collected, purified and distributed water |
| 23. Buildings | 45 | Construction works |
| 24. Rail transports | 601 | Rail transports |
| 25. Passenger transports | 6021 pt,6023 | Passenger transports by bus |
| | 6022 | Passenger transports by taxi |
| 26. Large truck transports | 6024 pt | Goods transports by trucks > 32 tons |
| 27. Medium truck transports | 6024 pt | Goods transports by trucks 3.5 - 32 tons |
| 28. Small truck transports | 6024 pt | Goods transports by trucks < 3.5 tons |
| 29. Sea transports | 61 | Sea transports |
| 30. Air transports | 620 | Air transports |
| 31. Other transports | 63 | Other transport products |
| | 64 | Communication products |
| 32. Services | 50-52 | Wholesale and retail trade products |
| | 55 | Restaurant and hotel services |
| | 65 | Financial services |
| | 66 | Insurance services |
| | 71-74 | Business services |
| | 75,80-85,90-95 | Other private services |
| 33. Dwellings | 70 | Real estate services |

* EU Classification of products by Activity (CPA).

**Table A3 Definition of commodities in private consumption**

| Commodity in EMEC | COICOP code* | Consumption label in the Swedish National Accounts |
|---|---|---|
| 1. Foods and beverages | 1,2 | Food, beverages and tobacco |
| 2. Clothing and footwear | 3 | Clothing and footwear |
| 3. Furniture etc | 51 | Furniture, carpets and repairs |
| | 52 | Household textiles and other furnishings |
| 4. Household goods | 531,532 | Major household appliances |
| | 54,55 | Glassware, tableware and household utensils |
| | 533 | Household services |
| 5. Gross rents | 41,42 | Gross rents and water charges |
| 6. Recreation | 9424 | Photographic equipment |
| | 9421-3,9425-7 | Entertainment and photo services |
| | 941,943 | Gambling, lotteries etc. |
| | 951-3 | Books, newspapers and magazines |
| | 914,931,932,9341 | Other recreational goods and services |
| 7. Private transport | 71,9211-3 | Personal transport equipment |
| | 721,7222 | Repair charges, parts and accessories |
| | 7241 | Compulsory tests of cars |
| 8. Road work trips | 7321 pt, 735-6 pt | Bus and local traffic, Cabs, Removal |
| 9. Road short leisure trips | 7321 pt, 735-6 pt | Bus and local traffic, Cabs, Removal |
| 10. Road long leisure trips | 7321 pt, 735-6 pt | Bus and local traffic, Cabs, Removal |
| 11. Rail work trips | 7310 pt | Railway transports |
| 12. Rail short leisure trips | 7310 pt | Railway transports |
| 13. Rail long leisure trips | 7310 pt | Railway transports |
| 14. Sea short leisure trips | 734 pt | Sea transports |
| 15. Sea long leisure trips | 734 pt | Sea transports |
| 16. Air long leisure trips | 733 pt | Air transports |
| | 960 | Services of travel agencies and air charter |
| 17. Services | 432 | Household services excl domestic services |
| | 562 | Domestic services |
| | 723,7241,7243-5 | Other expenditures on cars |
| | 81 | Communication |
| | 911 | Radio and television |
| | 915,923 | Repairs to recreational goods etc |
| | 935 | Veterinary services |
| | 11,121 | Services of barber and beauty shops etc |
| | 125,126 | Financial services |
| | 941,124,101 | Services n.e.c. |
| | 15 | Purchases abroad and foreign purchases |
| | 62,63 | Medical care and health expenses |
| 18. Goods n.e.c. | 912-3,921-2 | Other recreational goods |
| | 61,9342,1232 | Goods for personal care |
| | 431,561,551,933 | Goods n.e.c. |
| | 1212-3,954,12311 | Goods n.e.c |
| 19. Electricity | 451 | Electricity |
| 20. Gas | 452 | Gas |
| 21 Fuels | 453 | Heating oils |
| | 454 pt | Other fuels |
| 22. Gasoline work trips | 7221 pt | Gasoline |
| 23. Gasoline short leisure trips | 7221 pt | Gasoline |
| 24. Gasoline long leisure trips | 7221 pt | Gasoline |
| 25. Bio fuels | 454 pt | Other fuels |
| 26. Purchased heat | 455 | Purchased heat |

* COICOP (Classification of Individual Consumption by Purpose), is an international classification of private consumption according to A System of National Accounts (SNA), United Nations, 1993

**Table A4 Household groups**

| Household group | Household income | Region |
|---|---|---|
| Low income group in big city areas | 0 - 240 000 | H-region 1, 8, and 9: Stockholm, Gothenburg and Malmö |
| High income group in big city areas | 240 000 - ∞ | |
| Low income group in population centres | 0-240 000 | H-region 3: Municipalities with more than 90 000 inhabitants within a 30 km radius from the municipal centre and H-region 4: Municipalities with more than 27 000 and less than 90 000 inhabitants within a 30 km radius from the municipal centre and more than 300 000 inhabitants within a 100 km radius from the same point. |
| High income group in population centres | 240 000 - ∞ | |
| Low income group in sparsely populated areas | 0-240 000 | H-region 5: Municipalities with more than 27 000 and less than 90 000 inhabitants within a 30 km radius from the municipal centre and less than 300 000 inhabitants within a 100 km radius from the same point and H-region 6: Municipalities with less than 27 000 inhabitants within a 30 km radius from the municipal centre. |
| High income group in sparsely populated areas | 240 000 - ∞ | |

**Table A5 Definitions of energy carriers**

| Energy carrier | Label in the Swedish Environmental Accounts |
|---|---|
| Fuel oils | Domestic heating oil (EO1) |
| | Heavy fuel oils (EO2-5) |
| Gases | LPG |
| | Gas works gas |
| | Natural gas |
| | Coke oven gas |
| | Blast furnace gas |
| | LD-gas |
| Motor fuels | Motor gasoline |
| | Aviation gasoline |
| | Diesel oil |
| | Jet gasoline |
| | Jet kerosine |
| Coal | Coal |
| | Coke |
| Bio fuels | Wood-fuels |
| | Black liqour |
| | Tall oil |
| | Biogas |
| | Other biomass |
| Other fuels | Peat |
| | Wastes |
| | Other |

## A2. Variables and parameters

*Index*

| | |
|---|---|
| i | Production sectors |
| pr | Industry goods |
| e | Energy goods |
| f | Fuel types |
| gtr | Heavy freight transport |
| h | Household groups |
| hel | Houshold electricity |
| hheat | Household district heating |
| fn | Household goods |
| ne | Non-energy goods (households) |
| rents | Housing services |
| trh | Households' transport modes |
| trl | Transport mode for long trips |
| trp | Passenger transport modes |
| trs | Transport mode for short trips |
| trw | Transport mode for work trips |
| fno | Household goods not including transport services, energy or rents |
| po | Polluting emissions |

*Variables*

| | |
|---|---|
| *AT* | Hours worked, aggregate labour |
| *ATS* | Hours worked for skilled labour |
| *ATU* | Hours worked for unskilled labour |
| *B* | Current account |
| *C* | Capital stock |
| *CONS* | Matrix of consumption goods |
| *CS* | Sum of capital stock |
| *DZ* | Domestic demand in basic values |
| *E* | Demand of energy in basic values |
| *EBAR* | Restrictions on total emissions of $CO_2$, $SO_2$ and $NO_x$ |
| *EM* | Emissions of $CO_2$, $SO_2$ and $NO_x$ by industries |
| *EMH* | Emissions of $CO_2$, $SO_2$ and $NO_x$ by households |
| *EMTOTAL* | Total emissions of $CO_2$, $SO_2$ and $NO_x$ |
| *EXP* | Exports |
| *FRGT* | Aggretagte of heavy freight transport |
| *FRITRANS* | Aggregate of leisure trips |
| *FU* | Demand of fuels in basic values |
| *FUEL* | Fuel aggregate |
| *FV* | Value added in basic values |
| *HC* | Categories of private consumption |
| *HEAT* | Household demand of heating |
| *HOUSE* | Aggregate good housing |
| *IMP* | Imports, cif |
| *INSD* | Intermediate use of good |

| | |
|---|---|
| *INV* | Total gross investment |
| *INVS* | Sum of investments |
| *IO* | Intermediate demand of goods and services |
| *LA* | Changes in stocks |
| *LF* | Demand of liquid fuels in basic values |
| *LONG* | Long leisure trips |
| *LSK* | Supply of skilled labour |
| *LTOT* | Labour supply for each household |
| *LUNSK* | Supply of unskilled labour |
| *M* | Demand of materials in basic values |
| *ME* | Demand of the material-energy composite |
| *MET* | Emissions of metals by industries |
| *METH* | Emissions of metals by households |
| *NH3* | Emissions of nitrohydrogen in agriculture |
| *NINV* | Net investment by investing sector |
| *OUT* | Make matrix for produced commodities |
| *OVR* | Aggregate other goods and services |
| *PC* | Price on capital |
| *PD* | Domestic market prices incl. trade margins. |
| PDS | Price of composite commodity including taxes |
| *PDZ* | Basic prices of goods on domestic markets |
| *PE* | Price of energy |
| *PFRGT* | Price of aggregated heavy freight transport |
| *PFRITRANS* | Price of aggregate leisure trips |
| *PFU* | Price of fuels |
| *PFUEL* | Price of aggregate fuel |
| *PFV* | Price of value added |
| *PIMP* | Import price |
| *PHC* | Prices of various categories in private consumption excl. taxes |
| *PHCS* | Price of various categories in private consumption incl. taxes |
| *PHEAT* | Price of aggregate heating |
| *PHOUSE* | Price of aggregate housing |
| PINV | Price of investments |
| *PKL* | Private consumption |
| *PLA* | Price of stocks |
| *POVR* | Price of aggregate other goods and services |
| *PLONG* | Price of aggregate long leisure trips |
| *PLF* | Price of liquid fuels |
| *PM* | Price of materials |
| *PME* | Price of the material-energy composite |
| *PPK* | Private consumption |
| *PQ* | Prices of produced goods |
| *PQH* | Domestic price of produced goods |
| *PSFU* | Price of solid fuels |
| *PSHORT* | Price of aggregate short leisure trips |
| *PTP* | Price of transports |
| *PW* | Export market price |
| *PWORK* | Price of aggregate work trips |
| *Q* | Produced goods |

| | |
|---|---|
| *QG* | Public consumption |
| *QH* | Domestic demand of produced goods |
| *R* | Real rate of return, average level |
| *SFU* | Demand of solid fuels in basic values |
| *SHORT* | Short leisure trips |
| *T* | Traded goods |
| *TP* | Transport demand |
| *TRANSFERS* | Total transfers |
| *UTOT* | Household disposable income |
| *WM* | Index for export market |
| *WORK* | Work trips |
| *WT* | Hourly wages for aggrgate labour |
| *WTU* | Hourly wages for unskilled labour |
| *WTS* | Hourly wages for skilled labor |
| *WTT* | Hourly wages for technicians |
| *WTH* | Hourly wages for non-technicians |
| *PL* | Hourly wages for each household net of tax |
| *Z* | Production activity |

*Parameters*

| | |
|---|---|
| *ac* | Capital parameter in production function. |
| *ae* | Parameter in export function |
| *afv* | Value added parameter in production function |
| *ak*1, *ak*2, *ak*3 | Parameters in utility function |
| *al* | Labour parameter in production function |
| *alu* | Parameter for unskilled labour in aggregate labour |
| *als* | Parameter for skilled labour in aggregate labour |
| *alt* | Parameter for technicians in skilled labour |
| *alh* | Parameter for non-technicians in skilled labour |
| *am* | Parameter for imports in composite good |
| *ame* | Parameter for export of produced goods |
| *aq* | Parameter for domestic production in composite good |
| *atrw* | Parameter for transport modes in the utility of work trips |
| *atrs* | Parameter for transport modes in the utility of short leisure trips |
| *atrh* | Parameter for transport modes in the utility of long leisure trips |
| *along* | Parameter for long leisure trips in the utility of leisure trips |
| *ashort* | Parameter for short leisure trips in the utility of leisure trips |
| *afuel* | Parameter for various fuels in the utility of aggregate fuel |
| *aheat*1 | Parameter for aggregate fuel in the utility of heating |
| *aheat*2 | Parameter for electricity in the utility of heating |
| *aheat*3 | Parameter for district heating in the utility of heating |
| *ahouse*1 | Parameter for heat in the utility of housing |
| *ahouse*2 | Parameter for housing services in the utility of housing |
| *aovr* | Parameter for various goods in the utility of other goods and services |
| *be*1 | Parameter for oil in demand of liquid fuels |
| *be*2 | Parameter for electricity in the demand of energy |
| *be*3 | Parameter for gas in the demand of liquid fuels |
| *be*4 | Parameter for wood in the demand of solid fuels |
| *be*5 | Parameter for coal in the demand of solid fuels |

| | |
|---|---|
| *blf* | Parameter for liquid fuels in the demand of fuels |
| *bsf* | Parameter for solid fuels in the demand of fuels |
| *bf* | Parameter for fuels in the demand of energy |
| *bfrgt* | Parameter for freight |
| $bm_i$ | Parameter for materials |
| *btp* | Parameter for transports |
| β | Share of work trips needed for each unit of labour supply |
| *dep* | Depreciation rate |
| *emcoef* | Coefficients for emissions of $CO_2$, $SO_2$, $CO$, $NO_x$, $CH_4$, PM10 and PM25 use of fuels |
| *emcoefm* | Coefficients for emissions of $CO_2$, $SO_2$, $CO$, $NO_x$, $CH_4$, PM10 and PM25 use of materials |
| $fdeptshr_h$ | Household share of trade balance |
| *hm* | Trade margin in current prices |
| *hmk* | Trade margin in base-year prices |
| *insm* | Input coefficient for materials |
| *inv* | Composition of investment good |
| $invshr_h$ | Household share of trade balance |
| *itc* | Indirect taxes in consumption |
| *itce* | Energy tax in consumption |
| *itcmoms* | value added tax |
| *itcNOx* | Nitrogen oxide tax in consumption |
| *itcSO2* | Sulphur tax in production in consumption |
| *itcCO2* | Carbon tax in production in consumption |
| *itp* | Ad volorem net tax on inputs |
| *itpe* | Energy taxes in production |
| *itpKM* | Kilometre tax in production |
| *itpSO2* | Sulphur taxes in production |
| *itpCO2* | Carbon taxes in production |
| *la* | Composition of inventory good |
| *r* | Real rate of return distribution |
| *sat* | Elasticity of substitution between skilled and unskilled labour |
| *sats* | Elasticity of substitution between technicians and non-technicians |
| *sdz* | Elasticity of substitution between home and foreign goods in domestic use |
| *se* | Price elasticity of export demand |
| *sfv* | Elasticity of substitution between aggregate labour and capital |
| *swork* | Elasticity of substitution between modes used for work trips |
| *sshort* | Elasticity of substitution between modes used for short leisure trips |
| *slong* | Elasticity of substitution between modes used for long leisure trips |
| *sfritrans* | Elasticity of substitution between short and long leisure trips |
| *sfuel* | Elasticity of substitution between different fuels |
| *sheat* | Elasticity of substitution between electricity, district heating and fuels |
| *sfrgt* | Elasticity of substitution for heavy freight transport |
| *shouse* | Elasticity of substitution between heating and rents |

| | |
|---|---|
| *SKSHR* | Household share of skilled labour |
| *sovr* | Elasticity of substitution between different other goods and services |
| *slf* | Elasticity of substitution between oil and gas |
| *ssf* | Elasticity of substitution between wood and coal |
| *sf* | Elasticity of substitution between solid fuels and liquid fuels |
| *see* | Elasticity of substitution between fuels, hot water and electricity |
| *sme* | Elasticity of substitution between material and energy |
| *sz* | Elasticity of substitution between value added and the energy-material composite |
| *stp* | Elasticity of substitution for aggregate transports |
| *tpinsm* | Shares of aggregate transports in total use of materials and the energy carriers oil, coal and bio fuels |
| *tc* | Tax on capital |
| *tw* | Labour tax incl. employer's contribution to social security |
| *UNSKSHR* | Household share of unskilled labour |
| *wsk* | Wage cost distribution, skilled labour |
| *wuk* | Wage cost distribution, unskilled labour |

# Appendix B: Prices of household consumption

The price of a household's aggregate consumption, $PPK_h$, is given by :the following CES aggregation

$$PPK_h = \left[ \left( \frac{POVR_h}{ak3_h} \right)^{1-spk_h} + \left( \frac{PHOUSE_h}{ak1_h} \right)^{1-spk_h} + \left( \frac{PFRITRANS_h}{ak2_h} \right)^{1-spk_h} \right]^{1/1-spk_h}$$

Where:

$$POVR_h = \left[ \sum_{fno} \left( \frac{PHCS_{fno,h}}{aovr_{fno,h}} \right)^{1-sovr_h} \right]^{1/1-sovr_h}$$

$$PHOUSE_h = \left[ \left( \frac{PHCS_{rents,h}}{ahouse2_{rents,h}} \right)^{1-shouse_h} + \left( \frac{PHEAT_h}{ahouse1_h} \right)^{1-shouse_h} \right]^{1/1-shouse_h}$$

$$PFRITRANS_h = \left[ \left( \frac{PSHORT_h}{ashort_h} \right)^{1-sfritrans_h} + \left( \frac{PLONG_h}{ashort_h} \right)^{1-sfritrans_h} \right]^{1/1-sfritrans_h}$$

Where:

$$PSHORT_h = \left[ \sum_{trs} \left( \frac{PHCS_{trs,h}}{atrs_{trs,h}} \right)^{1-sshort_h} \right]^{1/1-sshort_h}$$

$$PLONG_h = \left[ \sum_{trh} \left( \frac{PHCS_{trh,h}}{atrs_{trh,h}} \right)^{1-slongi_h} \right]^{1/1-slong_h}$$

$$PHEAT_h = \left[ \left( \frac{PHCS_{hheat,h}}{aheat3_h} \right)^{1-sheat_h} + \left( \frac{PHCS_{hel,h}}{aheat2_h} \right)^{1-sheat_h} + \left( \frac{PFUEL_h}{aheat1_h} \right)^{1-sheat_h} \right]^{1/1-sheat_h}$$

Where:

$$PFUEL_h = \left[ \sum_f \left( \frac{PHCS_{f,h}}{afuel_{f,h}} \right)^{1-sfuel_h} \right]^{1/1-sfuel_h}$$

# Appendix C: CES functions

The CES function is frequently used in applied general equilibrium modelling to depict the behaviour of firms and households. The CES production function and its dual cost function are used to model substitution and demand of firms' inputs. The CES utility function and its dual expenditure function are used to model households' substitution and demand of commodities. Also, aggregate prices are derived from the cost function and the expenditure function. The CES functions used in the equations of the model EMEC are nested, i.e. the variables are aggregated at successively higher levels.

## C.1  CES production functions and factor demand

*Theory*

The outcome of optimal decisions in a static model can be summarized in a few equations. These will be illustrated by functions relating to optimal behaviour of a firm exhibiting a CES production function, but apply also to the CES utility function used for the modelling of household behaviour.

The CES production function $y()$ with the production factors labour $L$ and capital $K$ is often written on the following functional form:

$$y(L,K) = \alpha[\beta L^{\rho} + (1-\beta)K^{\rho}]^{1/\rho}$$

Assuming constant returns to scale (CRS) and no profits in production, cost minimization gives the dual minimum unit cost function expressed in prices with the elasticity of substitution $\sigma = 1/(1-\rho)$:

$$c(p_L, p_K) = \alpha^{-1}[\beta^{\sigma} p_L^{1-\sigma} + (1-\beta)^{\sigma} p_K^{1-\sigma}]^{1/(1-\sigma)}$$

The associated input demand for unit production is derived as the partial derivatives of the unit cost function by use of Shephard's lemma $\dfrac{\partial c(L)}{\partial p_L} = L$; $\dfrac{\partial c(K)}{\partial p_K} = K$.

In assuming CRS, the input demand functions will be:

$$L(p_L, p_K) = \alpha^{\sigma-1}\left[\frac{\beta\, c(p_L, p_K)}{p_L}\right]^{\sigma} y \; ; K(p_L, p_K) = \alpha^{\sigma-1}\left[\frac{(1-\beta)c(p_L, p_K)}{p_K}\right]^{\sigma} y$$

*The model EMEC*

Compared to the expressions given above, the CES aggregators of the model equations in EMEC are somewhat differently formulated. For example, the value-added aggregator corresponding to $y(L,K)$ is written:

$$FV(AT,C) = \left[(al \cdot AT)^{1-1/sfv} + (ac \cdot C)^{1-1/sfv}\right]^{\frac{1}{1-1/sfv}},$$

Where $FV$ is value added, $AT$ is hours worked, $C$ is capital stock, $sfv$ is elasticity of substitution and $al$, $ac$ are calibration constants. The associated minimum unit cost function $C$, thus, is :

$$C(WT, PC) = \left[(WT/al)^{1-sfv} + (PC/ac)^{1-sfv}\right]^{\frac{1}{1-sfv}}$$

The associated factor demand functions will be:

$$AT = al^{sfv-1} \cdot \left(\frac{C(WT,PC)}{WT}\right)^{sfv} FV \; ; \; C = ac^{sfv-1} \cdot \left(\frac{C(WT,PC)}{PC}\right)^{sfv} FV$$

By assuming no profits in equilibrium, the value added price $PFV$ must equal the unit cost $C(WT,PC)$, and the factor demand equations might be rewritten as they appear in the model:

$$AT = al^{sfv-1} \cdot \left(\frac{PFV}{WT}\right)^{sfv} FV \; ; \; C = ac^{sfv-1} \cdot \left(\frac{PFV}{PC}\right)^{sfv} FV$$

The assumption of no profits in production also gives the expression for a price aggregator in this example.

$$PFV = \left[(WT/al)^{1-sfv} + (PC/ac)^{1-sfv}\right]^{\frac{1}{1-sfv}}$$

This price aggregator as well as the aggregator for value added and the derived demand equations for labour and capital applies to all CES nested input equations of the model.

The relations between $al$, $ac$, $\alpha$ and $\beta$ are:

$$\alpha = \left[al^{1-1/sfv} + ac^{1-1/sfv}\right]^{\frac{1}{1-1/sfv}} \quad \text{and} \quad \beta = \frac{al^{1-1/sfv}}{al^{1-1/sfv} + ac^{1-1/sfv}}$$

The values of the constants $al$ and $ac$, are calibrated by solving the equations with benchmark data of the variables $FV$, $AT$, $C$, $PFV$, $AT$ and $PC$, given the substitution elasticity $sfv$,.

$$al = \left\{\frac{FV}{AT} \cdot \left[\frac{PFV}{WT}\right]^{sfv}\right\}^{\frac{1}{1-sfv}} \quad \text{and} \quad ac = \left\{\frac{FV}{C} \cdot \left[\frac{PFV}{PC}\right]^{sfv}\right\}^{\frac{1}{1-sfv}}$$

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