An Environmental Medium Term Economic Model – EMEC

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Abstract. This paper describes the structure of a new CGE model of the Swedish Economy called EMEC. The model can be used for analysing economic implications on a disaggregated level of changes in variables that are exogenous to the economy. It incorporates the interaction between the economy and the environment and can thus be used for analysing economic implications of various environmental restrictions such as the Kyoto agreement on CO_2 reductions. The model distinguishes 17 industries, 20 composite commodities, 19 groups of consumer goods, three kinds of labour and 15 pollutants. Apart from the level of disaggregation, the strength of the model is that it produces results, which can be interpreted fully in terms of the model's theory, data and the assumptions underlying the exogenous input.

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

1 Introduction

EMEC[1] is a computable general equilibrium model, CGE-model, of the Swedish economy developed and maintained by the National Institute of Economic Research for analysis of the interaction between the economy and the environment. EMEC is a static CGE-model with 17 industries and 20 composite commodities and a public sector producing a single commodity.[2] Produced goods are exported and used together with imports to create composite commodities for domestic use. Composites commodities are used as material and energy inputs by industries and for capital formation. In addition, households consume composite commodities and there are 19 groups of consumer goods.

Production requires primary factors (three kinds of labour and fixed capital) as well as inputs of materials and energy. Carbon dioxide (CO_2), carbon oxide (CO), methane (CH_4), sulphur dioxide (SO_2), nitrous oxide (N_2O) and nitrogen oxides (NO_x) as well as eight metals are emitted by the use of materials and fuel inputs in current production and by households' consumption of fuels (Agriculture also emit nitrohydrogen (NH_3)).

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.[3] Perfect competition and no economies of scale in production are assumed for all markets. Only one type of domestic consumer is present in the model. The model runs with exogenous interest

[1] Environmental medium term economic model.

[2] CGE modelling has been used by applied economists for many years 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., Parmenter, B.R, Powell, A. and Wilcoxen, P (1992).

[3] The model can alternatively be run with completely elastic factor supply (exogenous factor prices)

rate and is closed with an exogenous ratio for the foreign trade balance of the economy. Foreign trade is modelled with finite elasticities, and the foreign price level is chosen as numeraire.

The use of energy by firms or households is subject to energy tax and pollution taxes (the level of total emissions can also be bounded in the model). The tax exemptions for manufacturing are reflected in the estimated tax rates. Consumer goods are also subject to a value-added tax as well as other indirect taxes. There are also social security fees on the use of labour. 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 relativly dearer input or good.

The representative firm (or government agency) is assumed to choose an optimal mix of three types of labour in two stages and an optimal mix of energy in three stages. Then the firm decides upon the mix of labour and physical capital in the value added as well as the mix of energy and material in the energy-material input. At the highest level, it chooses the mix of value added and energy-material input to produce output. Another kind of substitution relates to goods of the same classification. Domestic goods can be substituted for foreign goods in foreign use (exports) and in domestic use (imports)[4]. Substitution is derived from CES-functions.

Aggregates and data of the model are presented in Section 2. All equations are given in Section 3. Calibration procedures and choice of parameter values are briefly discussed in Section 4. Technical definitions of goods and factors are given in Section 5, which also includes a complete list of variable names.

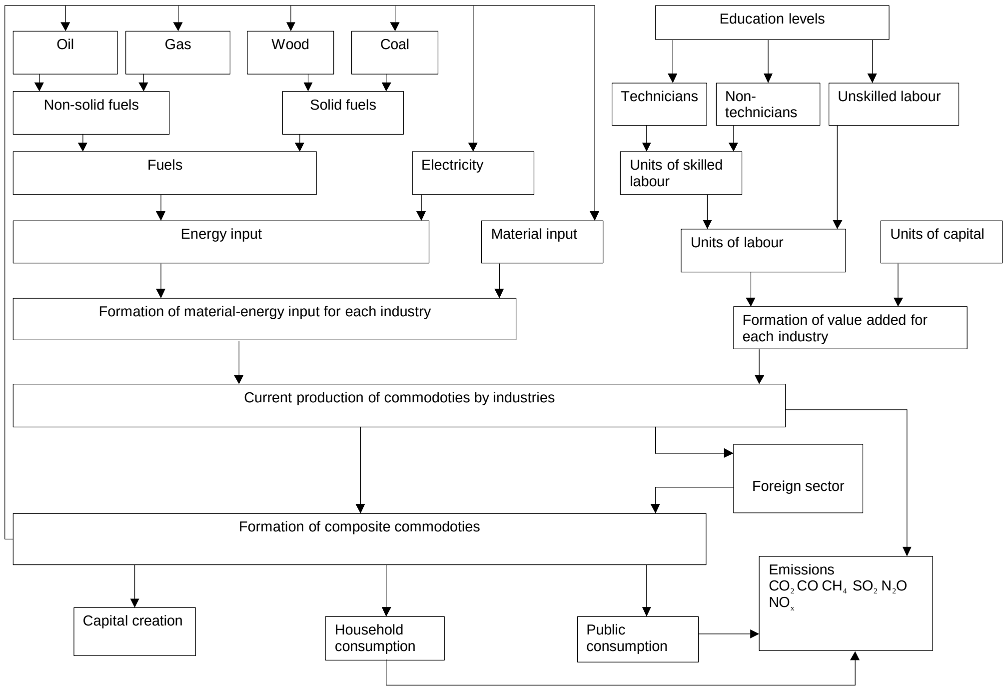
2 Aggregates and data of the model

The approach that has been chosen for the *EMEC* system implies that aggregates and specifications are adjusted to the application at hand. The rationale behind this approach is the desire to keep the model within manageable size and still preserve a potential for a wide range production sectors and factors of production. The database includes IO-data for 45 business sectors, which permits a sufficiently wide range of aggregation possibilities. Also, the detailed account for 13 types of labour according to educational status gives the *EMEC* system a potential for analysing issues related to the changing structure of the labour force. The present model distinguishes 18 producing sectors - 17 business sectors and a public sector. The sectors are: 1. Agriculture, 2. Fishery, 3. Forestry, 4. Mining, 5. Other industries, 6. Pulp and paper mills, 7. Chemical industries, 8. Basic metal industries, 9. Engineering, 10. Petroleum refineries, 11. Electricity supply, 12. Gas distribution, 13. Water and sewage, 14. Construction, 15. Transportation, 16. Services, 17. Real estate and 18. General and Local government. The 17 sectors produce 18 commodities in fixed proportions and twocommodities are not produced but imported. The model distinguishes among three types of labour; skilled technicians, skilled non-technicians and unskilled labour. Aggregation schemes, definitions and data sources are given in Section 5.

The relatively high intensity of skilled labour in the public sector implies that different growth rates for public services[5] may have substantial effects on the market for skilled labour and indirectly on the competitiveness of the most important exporting sector in the model economy. The potential competition for resources is even more evident in the market for real capital between the export oriented capital-intensive sector, the letting of dwellings and energy production. When the model is run with inter-sectoral, but not international, capital mobility, small changes in the demand for dwellings and energy may strongly affect the growth potential for the capital-intensive sector.

[4] This treatment of imports i general equilibrium modeling was pioneered by Armington (1969).
[5] Note that in the National Accounts, productivity growth is set to zero in the public sector.

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



*The arrows indicate the direction of flows.

3 Equations of the model

3.1 Final demands

Private consumption

It is assumed that a representative consumer chooses among different goods and services according to a CES utility function. Referring to section 5.3 the solution to the consumer's decision problem runs parallel to the producer's cost minimization problem. Derivation of the expenditure function, i.e. the minimal expenditure necessary to achieve a certain level of utility, gives the optimal demand for goods of consumption category HC_j as:

$$HC_j = ak_j^{spk-1} \cdot \left[\frac{PPK}{PHC_j \cdot itc_j} \right]^{spk} \cdot \frac{PKL}{PPK} \qquad , j = 1,\ldots,19 \qquad \textbf{(1)}^6$$

Where spk is the elasticity of substitution in the CES utility function, PKL is total consumer expenditures, PPK is the aggregate consumer price, PHC_j is the price of consumption category j, $PHC_j \cdot itc_j$ is the price of consumption category *j* including indirect taxes and ak_j is a calibration constant.[7]

[6]The index *j* relates to consumption categories and the index *i* to consumption goods.
[7]Note that according to the notational conventions stated in section 5.2 P is prefix to the names of price variables and L is suffix to the names of variables valued at current prices. The name of a variable valued at constant prices is without prefix or suffix. Names of aggregated variables are not indexed.

Consumption categories are aggregated to consumption goods PK_i by the matrix $CONS = \left[CONS_{ij} \right]$.

$$PK_i = \sum_{j=1}^{19} CONS_{ij} \cdot HC_j \quad ,i = 1,...,20$$

Fixed investment and changes in stocks

A kind of dynamics is sometimes introduced into CGE-models. Investment during one period is then transformed into capital stock in the next period. This step is, however, not taken in *EMEC* and hence the change in capital stock is net investments accumulated over all periods. The capital stock is assumed to grow at a uniform rate and this determines net investment in each sector, $NINV_i$, for the last 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:

$$INV_i = NINV_i + dep_i \cdot C_i \quad i = 1,...,18. \qquad \textbf{(2)}$$

Changes in stocks, LA, are exogenous.

Exports

Foreign and domestic consumers are assumed to differentiate between goods produced in Sweden and goods produced in other countries. This is often referred to as the Armington-assumption. The assumption, frequently made in CGE-modelling, does not fit very well into the common notion of Sweden as "a small open economy". We stick to this specification, however, as the model would otherwise generate an unrealistically strong specialisation in trade between countries. It is, however, not necessary to assume that Swedish producers have monopoly power in foreign markets, although Swedish goods are treated as imperfect substitutes for foreign goods. We can instead add the assumption that Swedish producers compete perfectly among themselves on all markets (which is not a very realistic assumption as the number of exporting firms is very small in each sector). In assuming differences between goods produced in Sweden and goods produced elsewhere, the number of goods in the model is expanded by the number of traded goods.

The export functions are:

$$EXP_i = \quad ae_i \cdot WM_i \cdot \left[\frac{PQ_i}{PW_i} \right]^{se_i} \quad .i = 1,...,20. \qquad \textbf{(3)}$$

where WM_i, PW_i and PQ_i are indices of export market size, export price level and domestic price level respectively, and se_i is the price elasticity of the demand curve. Although, Swedish and foreign goods of the same classification are not perfect substitutes, we can still make them close substitutes by assigning high elasticities to imports as well as to exports.

3.2 Input demands

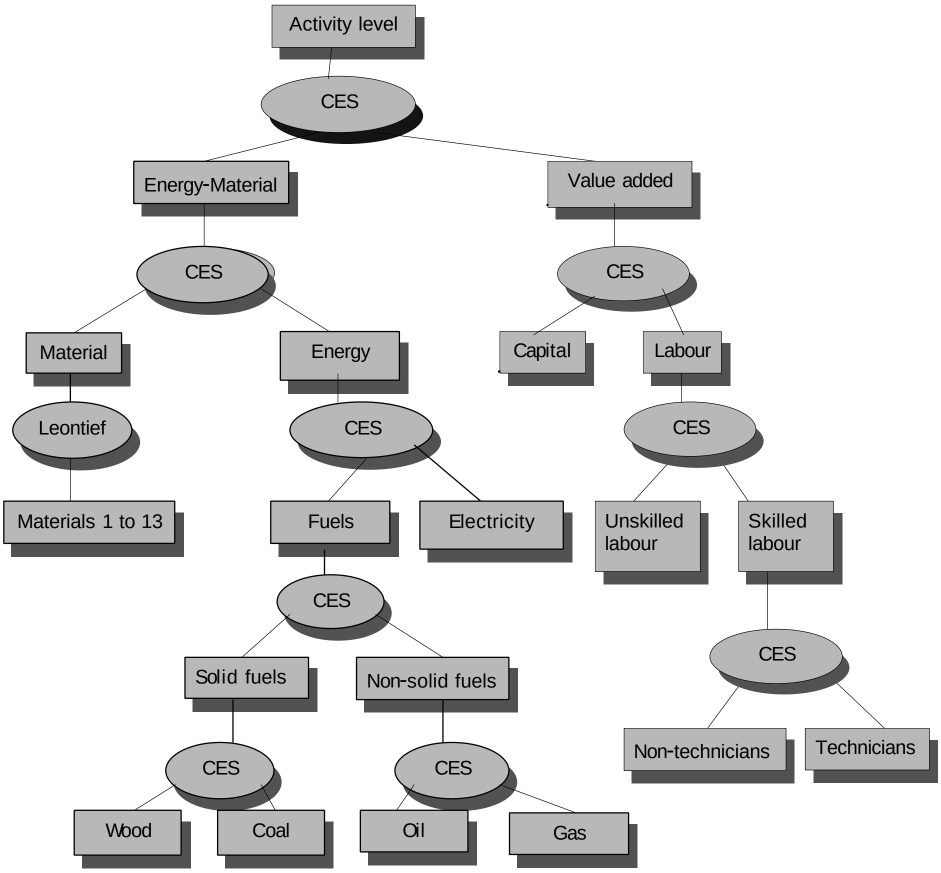
In each sector, including public services, gross output is produced using inputs of labour, capital, energy and materials. Figure 2 indicates the nested production structure.

Demand for energy and materials

CES-functions are used to combine wood (E4) and coal (E5) into solid fuels (SFU), as well as to combine oil (E1) and gas (E3) into liquid fuels (LF) at the first (lowest) aggregation level. Solid fuels and liquid fuels are then combined into fuels (FU) at the second CES-aggregation level.

Fuels and electricity (E5) are combined into energy (E) at the third CES-aggregation level. Materials (M) is a Leontief aggregation of all the intermediate inputs except energy inputs. The corresponding energy prices are PE4, PE5, PSFU, PE1, PE3, PLF, PFU, PE5, and PE, respectively. The substitution elasticities are *slf*, *ssf*, *sf*, and *see*. The calibration constants are *be1*, *be3*, *be4*, *be5*, *blf*, *bsf*, *be2*, and *bf*.

Figure 2 The input-activity specification in *EMEC*



Differentiation of the minimum cost per unit of liquid fuels LF_i gives sectoral demand for oil $E1_i$ and gas $E3_i$:

$$E1_i = be1_i^{slf_i - 1} \cdot \left(\frac{PLF_i}{PE1_i} \right)^{slf_i} \cdot LF_i \quad .i = 1,...,18. \tag{4}$$

$$E3_i = be3_i^{slf_i - 1} \cdot \left(\frac{PLF_i}{PE3_i} \right)^{slf_i} \cdot LF_i \quad .i = 1,...,18. \tag{5}$$

Differentiation of the minimum cost per unit of solid fuels SFU_i gives sectoral demand for wood $E4_i$ and coal $E5_i$:

$$E4_i = be4_i^{ssf_i - 1} \cdot \left(\frac{PSFU_i}{PE4_i} \right)^{ssf_i} \cdot SFU_i \quad .i = 1,...,18. \tag{6}$$

$$E5_i = be5_i^{ssf_i - 1} \cdot \left(\frac{PSFU_i}{PE5_i} \right)^{ssf_i} \cdot SFU_i \quad .i = 1,...,18. \qquad \textbf{(7)}$$

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

$$LF_i = blf_i^{sf_i - 1} \cdot \left(\frac{PFU_i}{PLF_i} \right)^{sf_i} \cdot FU_i \quad .i = 1,...,18. \qquad \textbf{(8)}$$

$$SFU_i = bsf_i^{sf_i - 1} \cdot \left(\frac{PFU_i}{PSFU_i} \right)^{sf_i} \cdot FU_i \quad .i = 1,...,18. \qquad \textbf{(9)}$$

Differentiation of the minimum cost per unit of energy E_i gives sectoral demand for electricity $E2_i$ and fuels FU_i:

$$E2_i = be2_i^{see_i - 1} \cdot \left(\frac{PE_i}{PE2_i} \right)^{see_i} \cdot E_i \quad .i = 1,...,8. \qquad \textbf{(10)}$$

$$FU_i = bf_i^{see_i - 1} \cdot \left(\frac{PE_i}{PFU_i} \right)^{see_i} \cdot E_i \quad .i = 1,...,18. \qquad \textbf{(11)}$$

The input coefficients, $insm_{ij}$, are defined as shares of total use of materials M_i and the intermediate demand of material j in sector i is:

$$INSD_j = insm_{ij} \cdot M_i \quad , \qquad \text{for all } j \neq 4,6,12,13,15. \qquad \textbf{(12)}$$

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 energy E_i:

$$M_i = bm_i^{sme_i - 1} \cdot \left(\frac{PME_i}{PM_i} \right)^{sme_i} \cdot ME_i \quad .i = 1,...,18. \qquad \textbf{(13)}$$

$$E_i = be_i^{sme_i - 1} \cdot \left(\frac{PME_i}{PE_i} \right)^{sme_i} \cdot ME_i \quad .i = 1,...,18., \qquad \textbf{(14)}$$

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 value added to gross 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:

$$ME_i = ame_i^{sz_i - 1} \cdot \left(\frac{\sum_j PQ_j \cdot OUT_{ij}}{PME_i} \right)^{sz_i} \cdot Z_i \quad .i = 1,...,18., \tag{15}$$

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

Demand for labour and capital

Each sector, including public services, uses three kinds of labour - unskilled labour, technicians and non-technicians - together with capital in a four-level CES production function[8]. Technicians and non-technicians are aggregated into skilled labour in the innermost nest. Then skilled labour and unskilled labour are aggregated into composite labour, which is used together with capital at the third level to create value added.

Differentiation of the minimum cost per unit of skilled labour ATS_i, with wages WTS_i, gives sectoral demand for each type of skilled labour ATT_i, with wages WTT_i, and ATH_i, with wages WTH_i,

$$ATT_i = alt_i^{sats_i - 1} \cdot \left[\frac{WTS_i}{WTT_i \cdot wtk_i} \right]^{sats_i} \cdot ATS_i \quad .i = 1,...,18. \tag{16}$$

$$ATH_i = alh_i^{sats_i - 1} \cdot \left[\frac{WTS_i}{WTH_i \cdot whk_i} \right]^{sats_i} \cdot ATS_i \quad .i = 1,...,18., \tag{17}$$

where $sats_i$ is the substitution elasticity, alt_i and alh_i, are calibration constants, wtk_i and wtk_i are indices for sectoral wage differences.

Differentiation of the minimum cost per unit composite labour AT_i, with wages WT_i, gives sectoral demand for each type of labour ATS_i and ATU_i with wages WTU_i:

$$ATS_i = als_i^{sat_i - 1} \cdot \left[\frac{WT_i}{WTS_i \cdot} \right]^{sat_i} \cdot AT_i \quad .i = 1,...,18. \tag{18}$$

$$ATU_i = alu_i^{sat_i - 1} \cdot \left[\frac{WT_i}{WTU_i \cdot wuk_i} \right]^{sat_i} \cdot AT_i \quad .i = 1,...,18. \tag{19}$$

Where sat_i is the substitution elasticity, als_i and alu_i, are calibration constants, and wuk_i is an index for sectoral wage differences.

[8] The different kinds of labour are defined in section 5.1.

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 price PC_i:

$$AT_i = al_i^{sfv_i - 1} \cdot \left(\frac{PFV_i}{(1+tw) \cdot WT_i} \right)^{sfv_i} \cdot FV_i \quad .i = 1,...,18. \tag{20}$$

$$C_i = ac_i^{sfv_i - 1} \cdot \left(\frac{PFV_i}{(1+tc) \cdot PC_i} \right)^{sfv_i} \cdot FV_i \quad .i = 1,...,18., \tag{21}$$

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

The highest CES-aggregation level combines the energy-materials composite and value added to gross output. Factor demand of value added is obtained by differentiation of the unit cost function:

$$FV_i = afv_i^{sz_i - 1} \cdot \left(\frac{\sum_j PQ_j \cdot OUT_{ij}}{PFV_i} \right)^{sz_i} \cdot Z_i \quad .i = 1,...,18. \tag{22}$$

3.3 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 19 (Private services), is:

$$DZ_i = INSD_i + PK_i + inv_i \cdot INV + la_i \cdot LA \quad ,i = 1,...,20. \tag{23}$$

where
$$INSD_4 = \sum_{j=1}^{18} E4_j, INSD_6 = \sum_{j=1}^{18} E5_j, \; INSD_{12} = \sum_{j=1}^{18} E2_j, INSD_{13} =$$
$$= \sum_{j=1}^{18} E3_j, INSD_{16} = \sum_{j=1}^{18} E1_j,$$

In order to obtain total domestic demand also for private services, we must add trade margins HMS to the expression in **(23)**. $INSD_i$ is intermediate use, PK_i is private consumption, $inv_i \cdot INV$ is investment, and $la_i \cdot LA$ is the change in stocks.

Demand for domestic output

Domestic consumers, including firms and producers of public services, are assumed to treat domestic goods as imperfect substitutes to imports of the same type of goods (cf. the section on imports). A CES-function, which constitutes an inner nest in the aggregation of different types of goods and services (CES for private consumption, describes this trade-off. Domestic demand for the produced good Q_i is derived from the unit cost function for the composite good DZ_i, with price PDZ_i, by using the usual optimality conditions. Adding exports EXP_i gives total demand for output:

$$Q_i = aq_i^{sdz_i - 1} \cdot \left(\frac{PDZ_i}{PQ_i} \right)^{sdz_i} \cdot DZ_i + EXP_i \qquad i = 1,...,20. \tag{24}$$

Where sdz_i is the substitution elasticity and aq_i is a calibration constant. Note that production (or consumption) in the public sectors is exogenous.

Demand for imports

As with domestic demand for output, $aq_i^{sdz_i - 1} \cdot \left(\frac{PDZ_i}{PQ_i} \right)^{sdz_i} \cdot DZ_i$, demand for imports of good IMP_i, at prices $PIMP_i$, is obtained from the unit cost function of the composite good:

$$IMP_i = am_i^{sdz_i - 1} \cdot \left(\frac{PDZ_i}{PIMP_i} \right)^{sdz_i} \cdot DZ_i \qquad i = 1,...,20., \tag{25}$$

where sdz_i is the substitution elasticity and am_i is a calibration constant.

3.4 Emissions of pollutants

Carbon dioxide (CO_2), sulphur dioxide (SO_2) and nitrogen oxides (NO_x) as well as the metals lead (Pb), zinc (Zn), nickel (Ni), coper (Cu), chrome (Cr), arsenic (As), cadmium (Cd) and mercury (Hg) are emitted by production in the use of materials and fuel inputs and by households in the consumption of fuels. Agriculture also emit nitrohydrogen (NH_3).

The model evaluates the emissions of (CO_2), (SO_2) and (NO_x) 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 and NO_x in the use of energy and materials in production are given by:

$$\begin{aligned} EM_i = & \sum_j emcoef1_{i,j} \cdot E1_j + \sum_j emcoef3_{i,j} \cdot E3_j + \\ & + \sum_j emcoef4_{i,j} \cdot E4_j + \sum_j emcoef5_{i,j} \cdot E5_j + \\ & + \sum_j emcoefm_{i,j} \cdot M_j, \qquad i = CO_2, SO_2, NO_x, \end{aligned} \tag{26}$$

where $emcoef1_{i,j},...,emcoefm_{i,j}$ are coefficients for emission of CO_2, SO_2 and NO_x in the use of energy carriers and materials $E1_{i,j},...,Em_{i,j}$ in sector j.

Total emissions of CO_2, SO_2 and NO_x in the use of energy by households are given by:

$$EMH_i = emhcoef\ 16_i \cdot HC16 + emhcoef\ 15_i \cdot HC15 + \\ + emhcoef\ 17_i \cdot HC17 + emhcoef\ 18_i \cdot HC18, \\ i = CO_2, SO_2, NO_x, \tag{27}$$

where $emhcoef16_i$ are the coefficients for emission of CO_2, SO_2 and NO_x in private consumption of the commodity $HC16$ (Fuels).

The model evaluates the emissions of (Pb), (Zn), (Ni), (Cu), (Cr), (As), (Cd) and (Hg) as a function of the energy use and the material input for industries and energy consumption for households.

Total emissions in the use of energy and materials in production are calculated as:

$$MET_i = \sum_j metcoef1_{i,j} \cdot E1_j + \sum_j metcoef3_{i,j} \cdot E3_j + \\ + \sum_j metcoef4_{i,j} \cdot E4_j + \sum_j metcoef5_{i,j} \cdot E5_j + \\ + \sum_j metcoefm_{i,j} \cdot M_j \ , i = Pb, Zn, Ni, Cu, Cr, As, Cd, Hg. \tag{28}$$

The total emissions as a function of the energy consumption for households is given by:

$$METH_i = methcoef16_i \cdot HC16 + methcoef15_i \cdot HC15 + \\ + methcoef17_i \cdot HC17 + methcoef18_i \cdot HC18, \\ i = Pb, Zn, Ni, Cu, Cr, As, Cd, Hg. \tag{29}$$

The model also evaluates the emissions of (NH_3) as a function of the activity level in Agriculture:

$$NH3 = nh3coef \cdot Z1 \tag{30}$$

3.5 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. Also the supply of imports is completely elastic, and the prices of imports are exogenous.

WTT, WTH and WTU are equilibrium wages on the three labour markets. The three 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, wtk, whk and wuk, are kept unchanged in simulations. For each sector the wage cost per hour of skilled labour WTS_i is given by:

$$WTS_i = \left[\left(\frac{WTT \cdot wtk_i}{alt_i} \right)^{1-sats_i} + \left(\frac{WTH \cdot whk_i}{alh_i} \right)^{1-sats_i} \right]^{\frac{1}{1-sats_i}}, i = 1,...,18 \tag{31}$$

and the wage cost per hour of aggregated labour WT_i is given by:

$$WT_i = \left[\left(\frac{WTS_i \cdot}{als_i} \right)^{1-sat_i} + \left(\frac{WTU \cdot wuk_i}{alu_i} \right)^{1-sat_i} \right]^{\frac{1}{1-sat_i}}, \; i = 1,\dots,18 \qquad \textbf{(32)}$$

The price of capital PC_i is defined as the cost of using one unit of physical capital valued at constant prices:

$$PC_i = [r_i \cdot R + dep_i] \cdot PINV \quad , i = 1,\dots,18. \qquad \textbf{(33)}$$

where R is the average level of the real rate of return before taxes. The distribution of return to capital among sectors, r_i, is exogenous and as the distributions of wages it can be observed for the calibration year .[9]

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 $(1+tw)$ and $(1+tc)$:

$$PFV_i = \left[\left(\frac{(1+tw) \cdot WT_i}{al_i} \right)^{1-sfv_i} + \left(\frac{(1+tc) \cdot PC_i}{ac_i} \right)^{1-sfv_i} \right]^{\frac{1}{1-sfv_i}} . i = 1,\dots,18. \qquad \textbf{(34)}$$

The basic price of the composite good in domestic use PDZ_i is calculated from the import price $PIMP_i$ and the price of domestic commodities in basic values PQ_i according to the assumed CES-aggregation:

$$PDZ_i = \left[\left(\frac{PIMP_i}{am_i} \right)^{1-sdz_i} + \left(\frac{PQ_i}{aq_i} \right)^{1-sdz_i} \right]^{\frac{1}{1-sdz_i}} . i = 1,\dots 20. \qquad \textbf{(35)}$$

PDZ_i is the price of good i on domestic markets when it leaves the combined plant-import harbour. Trade margins and commodity taxes are added to the 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.[10] 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.

It is assumed that the price of trade margins follows the domestic price of the commodity 19 Private services, PDZ_{19}, rather than the price of the commodity itself. This seems a reasonable assumption in the medium and long run. Domestic prices PD_i including trade margins are:

[9]This formulation of the model is dubious as is 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.

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

$$PD_i = (PDZ_i + hm_i \cdot PDZ_{19})/(1 + hmk_i) \quad , \quad i = 1,...,20. \qquad \textbf{(36)}$$

Trade margins can be changed exogenously by the parameter hm_i. The hmk_i's are calibration constants.

Commodity taxes leaved on the inputs of production include VAT, other indirect commodity taxes and subsidies, energy tax, and carbon and sulphur taxes. The taxes on energy and environmental taxes 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:

$$PE1_i = PD_{15} \cdot (1 + itp_{15}) + itpe_{15,i} + itpSO2_{15,i} + itpCO2_{15,i} \qquad \textbf{(37)}$$

$$PE2_i = PD_{12} \cdot (1 + itp_{12}) + itpe_{12,i} + itpSO2_{15,i} + itpCO2_{15,i} \qquad \textbf{(38)}$$

$$PE3_i = PD_{13} \cdot (1 + itp_{13}) + itpe_{13,i} + itpSO2_{15,i} + itpCO2_{15,i} \qquad \textbf{(39)}$$

$$PE4_i = PD_6 \cdot (1 + itp_6) + itpe_{6,i} + itpSO2_{15,i} + itpCO2_{15,i} \qquad \textbf{(40)}$$

$$PE5_i = PD_4 \cdot (1 + itp_4) + itpe_{4,i} + itpSO2_{15,i} + itpCO2_{15,i} \qquad \textbf{(41)}$$

$$PM_i = \sum_{k \neq 4,6,12,13,15} PD_k \cdot (1 + itp_k) \cdot insm_{k,i} \qquad \textbf{(42)}$$

for $i = 1,...,18.$,

where itp_{15} is the ad volorem net tax on inputs of oil and $itpe_{15,i}$, $itSO2_{15,i}$, and $itCO2_{15,i}$ are energy tax, sulphur tax, and carbon tax, respectively, on oil. The energy tax and the environmental taxes are specific to various industries so as to allow for tax exemptions.

PE4, PE5, PE1, PE3, and *PE2* are equilibrium prices, including taxes, on the goods markets for the five types of energy carriers. For each sector the unit cost of aggregate energy PE_i is given by:

$$PE_i = \left[\left(\frac{PFU_i}{bf_i} \right)^{1-see_i} + \left(\frac{PE2_i}{be2_i} \right)^{1-see_i} \right]^{\frac{1}{1-see_i}} \quad ,i = 1,...,18, \qquad \textbf{(43)}$$

where:

$$PFU_i = \left[\left(\frac{PLF_i}{blf_i} \right)^{1-sf_i} + \left(\frac{PSFU_i}{bsf_i} \right)^{1-sf_i} \right]^{\frac{1}{1-sf_i}} \quad ,i = 1,...,18, \qquad \textbf{(44)}$$

and

$$PLF_i = \left[\left(\frac{PE1_i}{be1_i} \right)^{1-slf_i} + \left(\frac{PE3_i}{be3_i} \right)^{1-slf_i} \right]^{\frac{1}{1-slf_i}} \quad ,i = 1,\ldots,18, \tag{45}$$

$$PSFU_i = \left[\left(\frac{PE4_i}{be4_i} \right)^{1-ssf_i} + \left(\frac{PE5_i}{be5_i} \right)^{1-ssf_i} \right]^{\frac{1}{1-ssf_i}} \quad ,i = 1,\ldots,18, \tag{46}$$

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 and the indirect commodity taxes itp_{15}, $itpe_{15,i}$, $itSO2_{15,i}$, $itCO2_{15,i}$, and $itNOX_{15,i}$:

$$PME_i = \left[\left(\frac{PM_i}{bm_i} \right)^{1-sme_i} + \left(\frac{PE_i}{be_i} \right)^{1-sme_i} \right]^{\frac{1}{1-sme_i}} \quad .i = 1,\ldots,18. \tag{47}$$

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

$$\sum_j PQ_j \cdot OUT_{ij} = \left(PFV_i \cdot FV_i + PME_i \cdot ME_i \right) / Z_i \qquad ,i = 1,\ldots,18. \tag{48}$$

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, $itce_i$, carbon tax, $itcCO2_i$, sulphur tax, $itcSO2_i$ and other indirect taxes and subsidies, $itci_i$. Prices of consumer categories, including indirect commodity taxes, $PHC_i \cdot itc_i$, are given by:

$$\begin{aligned} PHC_i \cdot itci_i = &(1 + itcmoms_i)(itce_i + itcSO2_i + itcCO2_i + \\ &+ (1 + itci_i) \cdot PHC_i) \end{aligned} \tag{49}$$

for $i = 1,\ldots,19$ and where:

$$PHC_i = \sum_j PD_j \cdot CONS_{ij} \quad ,i = 1,\ldots,19$$

The consumer price index PPK can be calculated as:

$$PPK = \sum_{i=1}^{19} PHC_i \cdot itc_i \cdot HC_i \bigg/ \sum_{i=1}^{19} HC_i \ . \tag{50}$$

Investments in all sectors are assumed to consist of the same Leontief composite good making the aggregate price $PINV$ of the common investment good equal to:

$$PINV = \sum_{i=1}^{20} inv_i \cdot PD_i \tag{51}$$

Finally the price of investments in stocks is:

$$PLA = \sum_{i=1}^{20} la_i \cdot PD_i \qquad \textbf{(52)}$$

3.6 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 version of *EMEC* used for the Medium Term Survey (MTS). 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 model is run with exogenous labour supply when applied for the (MTS).

The equilibrium conditions simply state that demand equals supply of production factors *LST*, *LSH*, *LSU* and *CS*:

$$LSH = \sum_{i=1}^{18} ATH_i \quad . \qquad \textbf{(53)}$$

$$LST = \sum_{i=1}^{18} ATT_i \quad . \qquad \textbf{(54)}$$

$$LSU = \sum_{i=1}^{18} ATU_i \qquad \textbf{(55)}$$

$$CS = \sum_{i=1}^{18} C_i \qquad \textbf{(56)}$$

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 PKL in (1) must be determined. This can be accomplished by letting either household savings or the current account (trade balance) or the gross-savings ratio 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, $EBAR_i$:

$$EMTOTAL_i \leq EBAR_i \qquad , i = CO_2, SO_2, NO_x . \qquad \textbf{(57)}$$

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. *EMEC* can be calibrated for different years and with any year serving 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 freedom to choose the calibration year is potentially important. The usual calibration procedure assumes, often without explicit discussion, that the economy is in equilibrium for the calibration year. There is often a desire to choose the latest year for which data exist when calibrating the model. This desire might conflict with the assumption of an economy in equilibrium. The calibration procedure and the time seriesdata base of *EMEC* give us the opportunity to test the importance of the choice of calibration year.

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-aggregators must be specified before calibration. The figures given in Table 1 are used in the present version of the model.

Table 1 Substitution elasticities in production sectors

Production sector	Sats	sat	sfv	sz	sme	see	sf	slf	ssf
1. Agriculture	1,7	1,1	0,5	0,3	0,5	0,6	0,7	0,8	0,9
2. Fishery	1,7	1,1	0,5	0,2	0,3	0,4	0	0	0
3. Forestry	1,7	1,1	0,5	0,3	0,4	0,5	0	0	0
4. Mining	1,7	1,1	0,8	0,3	0,4	0,5	0,6	0	0
5. Other industries	1,7	1,1	0,8	0,3	0,4	0,5	0,6	0,7	0,8
6. Pulp and paper mills	1,7	1,1	0,8	0,7	0,9	1,1	1,2	1,3	1,4
7. Chemical industries	1,7	1,1	0,8	0,7	0,9	1,1	1,2	1,3	1,4
8. Basic metal industries	1,7	1,1	0,8	0,7	0,9	1,1	1,2	1,3	1,4
9. Engineering	1,7	1,1	0,8	0,7	0,9	1,1	1,2	1,3	1,4
10. Petroleum refineries	1,7	1,1	0,3	0,2	0,3	0,5	1,1	1,5	1,8
11. Electricity supply	1,7	1,1	0,3	0,2	0,3	0,4	0	0	0
12. Gas distribution	1,7	1,1	0,3	0,2	0,3	0,4	0	0	0
13. Water and sewage	1,7	1,1	0,2	0,1	0,2	0,3	0	0	0
14. Construction	1,7	1,1	0,3	0,2	0,3	0,7	0	0	0
15. Transportation	1,7	1,1	0,8	0,6	0,7	0,8	0	0	0
16. Services	1,7	1,1	0,8	0,7	0,9	1,1	1,2	1,3	0
17. Real estate	1,7	1,1	0,6	0,5	0,8	1,2	0	1,5	0
18. Public services	1,7	1,1	0,7	0,1	0,7	1,1	1,2	1,3	0

Table 2 Elasticities of commodities in foreign trade

Commodity	sdz	se
1. Agricultural products	0,4	-2
2. Fish	0,4	-2
3. Timber	0,4	-3
4. Bio fuels	0,4	-5
5. Metal ores and stone	0,6	-5
6. Coal	0,3	-5
7. Products n.e.c.	0,7	-3
8. Pulp and paper	1,1	-5
9. Chemical products	0,8	-3
10. Basic metals	0,1	-4
11. Metal products, machinery and equipment	0,7	-3
12. Electricity	0,1	-3
15. Petroleum products	0,6	-3
16 Crude petroleum	0,6	-2
17. Building	0,2	-1
18. Transport services	1,1	-3

19. Business and private services	0,9	-3

There seems to be some consensus in the empirical literature for labour-capital substitution elasticities between 0.5 and 1.0 (see e.g. Caddy [1976] and Bovenberg, L.A., and Gouldner, L.H. [1996]). The distinction between different kinds of labour is not very common in CGE-modelling. Moreover, the elasticity might depend on the definitions of labour categories. The only basis for the numbers given in the table is a series of simulations in which the shares of skilled labour and of technicians were altered over a 10-year period. When elasticities are low, the relative wages are compressed too fast. The substitution elasticity in private consumption is 0.8.

The price elasticities of exports in Table 2 are chosen fairly high for the competing sectors to avoid terms-of-trade effects that are overly strong in the scenario applications.

5 Conclusions: future developments

This paper describes a new model of the Swedish economy called EMEC, which has been developed at the National Institute of Economic Research for medium term analysis of the economy and its environmental interactions. The model has so far been used in the 1999 MTS and by committees analysing the economic implications of the Kyoto agreement on CO_2 restrictions.

The strength of the model is that it produces results on a disaggregated economic level consistent with the model's theory, data and the assumptions underlying the exogenous input. Its main weakness is that industry structure and household behaviour are not modelled in enough detail to give the full economic picture of adapting to environmental restrictions. This will be taken care of in future developments of the model, which will also incorporate various abatement processes.

Appendix A: CES Functions

A.1 CES production functions and factor demand

CES-functions are frequently used to model substitution. The outcome of optimal decisions in a static model can be summarized in a few formulas. These will be illustrated by functions relating to optimal behaviour of a firm exhibiting a CES production function, but apply in principal also to the CES utility function. The value-added aggregator is written:

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

where *FV* is value added, *AT* is hours worked, *C* is capital stock, *sfv* is elasticity of substitution and *al, ac* are calibration constants.

Labour and capital are assumed to be fully mobile between production sectors and all sectors exhibit constant returns to scale. It can be shown that the minimum cost to produce the quantity *FV* is:

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

In perfect competition no profits exist in equilibrium, i.e.:

*CFV=PFV*FV*

Applying Shephard's lemma:

$$AT = FV \cdot \frac{\partial PFV}{\partial WT} \quad \text{and} \quad C = FV \cdot \frac{\partial PFV}{\partial PC}$$

yielding factor demand:

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

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

The CES-function is often specified in a slightly different way as:

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

In this case:

$$CFV = \frac{1}{a} \cdot \left[b^{sfv} \cdot WT^{1-sfv} + (1-b)^{sfv} \cdot PC^{1-sfv} \right]^{\frac{1}{1-sfv}} \cdot FV$$

$$AT = a^{sfv-1} \cdot \left(b \cdot \frac{PFV}{WT} \right)^{sfv} \cdot FV \text{ and } C = a^{sfv-1} \cdot \left((1-b) \cdot \frac{PFV}{PC} \right)^{sfv}$$

$$\frac{AT}{C} = \left(\frac{b \cdot PC}{(1-b) \cdot WT} \right)^{sfv}$$

The relations between *al*, *ac*, α and β are:

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

A.2 Calibration of factor demand functions

Recall the CES-aggregator for value added:

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

This function includes the constants *al*, *ac* and the substitution elasticity *sfv*. Assuming the economy is in equilibrium, optimal factor demand is:

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

These expressions can be solved for *al* and *ac*:

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

where:

FV = value-added
PFV = implicit price of value-added
AT = hours worked
WT = compensation of employees including employers' contribution to social security
C = capital stock in constant prices
PC = compensation of capital incl. depreciation and taxes per unit capital in constant prices

Given *sfv*, we can calculate *al* and *ac* for the calibration year.

Appendix B: Definitions and Variables

B.1 Definitions and data sources

Sector classification

EMEC distinguishes between 18 producing sectors - 17 business sectors plus a public sector. Table B1 gives the exact definitions of sectors in the disaggregated database. All variables related to production are taken from the National Accounts (N A). The basic IO-table is from 1993.

Table B1 Definition of private production sectors

Production sector	SNR-code	Sector label in National Accounts
1. Agriculture	1100	Agriculture and hunting
2. Fishery	1300	Fishing
3. Forestry	1200	Forestry and logging
4. Mining	2100	Iron ore mining
	2200	Non-ferrous ore mining
	2900	Other mining and quarrying
5. Other industries	3100	Manufacture of food, beverage and tobacco
	3200	Textile industries
	3300	Manufacture of wood and wood products
	3600	Manufacture of non-metallic mineral products
6. Pulp and paper mills	3410	Manufacture of pulp
	3420	Manufacture of paper and paperboard
	3430	Products of pulp, paper and paperboard
	3410	Printing and publishing
7. Chemical industries	3510	Manufacture of industrial chemicals
	3520	Manufacture of other chemical products
	3550	Manufacture of rubber products
	3560	Manufacture of plastic products
8. Basic metal industries	3710	Iron steel basic industries
	3720	Non-ferrous metal basic industries
9. Engineering	3810	Manufacture of metal products
	3820	Manufacture of machinery
	3830	Manufacture of electric machinery
	3840	Manufacture of transport equipment
	3850	Manufacture of measuring equipment, etc
	3860	Ship building and repairing
	3900	Other manufacturing industries
10. Petroleum refineries	3530	Petroleum refining
11. Electricity supply	4100	Electricity, steam and hot water supply
12. Gas distribution	4200	Gas manufacture and distribution
13. Water and sewage	4300	Water supply and sewage isposal
14. Construction	5000	Construction
15. Transportation	7100	Transport and storage
	7200	Communication
16. Services	6100	Wholesale and retail trade
	6300	Restaurants and hotels
	8100	Financial institutions
	8200	Insurance
	8320	Business services
	9000	Other private services
17. Real estate	8310	Letting of dwellings and other real estate

Commodity classification

EMEC distinguishes between 20 commodities, which are produced and/or imported. Table B2 presents the exact definitions of list of sectors in the disaggregated database. All variables related to production are taken from N A. The basic IO-table is from 1993.

Table B2 Definition of commodities

Commodity	SNR-code	Sector label in National Accounts
1. Agricultural products	1100	Agriculture and hunting
2. Fish	1300	Fishing
3. Timber	1200	Forestry and logging
4. Bio fuels	1200	Forestry and logging
5. Metal ores and stone	2100	Iron ore mining
	2200	Non-ferrous ore mining
	2900	Other mining and quarrying
6. Coal	2900	Other mining and quarrying
7. Products n.e.c.	3100	Manufacture of food, beverage and tobacco
	3200	Textile industries
	3300	Manufacture of wood and wood products
	3600	Manufacture of non-metallic mineral products
8. Pulp and paper	3410	Manufacture of pulp
	3420	Manufacture of paper and paperboard
	3430	Products of pulp, paper and paperboard
	3410	Printing and publishing
9. Chemical products	3510	Manufacture of industrial chemicals
	3520	Manufacture of other chemical products
	3550	Manufacture of rubber products
	3560	Manufacture of plastic products
10. Basic metals	3710	Iron steel basic industries
	3720	Non-ferrous metal basic industries
11. Metal products,	3810	Manufacture of metal products
Machinery and	3820	Manufacture of machinery
Equipment	3830	Manufacture of electric machinery
	3840	Manufacture of transport equipment
	3850	Manufacture of measuring equipment, etc.
	3860	Ship building and repairing
	3900	Other manufacturing industries
12. Electricity	4100	Electricity, steam and hot water supply
13. Gas	4200	Gas manufacture and distribution
14. Fresh water	4300	Water supply and sewage disposal
15. Petroleum products	3530	Petroleum refining
16. Crude petroleum	2900	Other mining and quarrying
17. Building	5000	Construction
18. Transport services	7100	Transport and storage
	7200	Communication
19. Business and	6100	Wholesale and retail trade
private services	6300	Restaurants and hotels
	8100	Financial institutions
	8200	Insurance
	8320	Business services
	9000	Other private services
20. Dwellings	8310	Letting of dwellings and other real estate

Classification of private consumption

EMEC distinguishes between 19 categories of private consumption – energy carriers are consumption categories 14-19. Table B3 gives the exact definitions of sectors in the disaggregated database. All variables related to production are taken from N A.The basic IO-table is from 1993.

Table B3 Definition of commodities in private consumption

Commodity	SNR-code	Label in National Accounts
1. Food, beverage and tobacco	1000	Food, beverages and tobacco
2. Clothing and footwear	2000	Clothing and footwear
3. Furniture etc	4100	Furniture, carpets and repairs
	4200	Household textiles and other furnishings
4. Household goods	4300	Major household appliances
	4400	Glassware, tableware and household utensils
	4510	Household services
5. Gross rents	3100	Gross rents and water charges
6. Recreation	7121	Photographic equipment
	7130	Other recreational goods
	7211	Entertainment and photo services
	7213	Gambling, lotteries etc.
	7300	Books, newspapers and magazines
	8300	Expenditure in restaurants, cafés and hotels
7. Private transport	6100	Personal transport equipment
	6210	Repair charges, parts and accessoires
	6231	Compulsory tests of cars
8. Road transports	6320	Bus and local traffic
	6340	Cabs
	6380	Removal
9. Railways	6310	Railways
10. Ships	6350	Ships
11. Airlines	6360	Airlines
	6370	Services of travel agencies and air charter
12. Services	4520	Household sevices excl domestic services
	4600	Domestic services
	6230 excl 6231	Other expenditures on cars
	6400	Communication
	7110	Radio and television
	7140	Repairs to recreational goods etc
	7212	Television licences
	7214	Veterinary services
	8110	Services of barber and beauty shops etc
	8500	Finacial services
	8600	Services n.e.c.
	9000	Purchases abroad and foreigners´ purchases
13. Goods n.e.c.	5000	Medical care and helth expenses
	7130	Other recreational goods
	8120	Goods for personal care
	8200	Goods n.e.c.
14. Electricity	3210	Electricity
15. Gas	3220	Gas
16 Fuels	3230	Liquid fuels
	Pt 3240	Other fuels
17. Gasoline	6220	Gasoline
18. Bio fuels	Pt 3240	Other fuels
19. Purchased heat	3250	Purchased heat

Labour categories

The distribution of different kinds of labour across sectors is taken from different statistical sources. The pooling of data was carried out by Statistics Sweden and includes educational data, industry data and income data. This part of the database includes the distribution of 13 labour categories among the 47 production sectors. For each category of labour the number of persons employed per sector and their labour income is available. The labour categories are defined according to their level and type of education. The definition of unskilled labour includes those with high school or a lower level of education. In skilled labour we distinguishes between those with technical education (including technical high school) and the so called non-technicians. All employment and income figures are adjusted to N A levels by simple scaling. A major obstacle in computing hourly wages is that there is no information on hours worked in the pooled data. No attempt is made to adjust for the possible bias in the computed hourly earning levels.

Factor prices

Wages are defined as labour cost per hour. Wages for aggregate labour are taken from N A. Capital cost, PC, is defined per unit of physical capital valued at 1991 prices and is computed from N A as gross operating surplus OS divided by the capital stock C:

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

$PFV \cdot FV$ 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, d, 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:

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

B.2 Variables and parameters

Only some variables and parameters are indexed in the equations of the model. Indices are explained in connection with the presentation of equations.

Variables

AT	Hours worked, aggregate labour.
ATU	Hours worked for unskilled labour.
ATS	Hours worked for skilled labour.
ATT	Hours worked for technicians.
ATH	Hours worked for non-technicians.
C	Capital stock.
DZ	Domestic demand in basic values.
E	Demand of energy in basic values.
$E1,...,E5$	Demand of oil, electricity, gas, wood and coal, respectively 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.
FU	Demand of fuels in basic values.
FV	Value added in basic values.
HC	Categories of private consumption
IMP	Imports, cif.
$INSD$	Intermediate use of good.
$NINV$	Net investment by investing sector.
INV	Total gross investment.
LF	Demand of liquid fuels in basic values.
LA	Changes in stocks.
LSU	Supply of unskilled labour.
LST	Supply of technicians.
LSH	Supply of non-technicians.
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
PC	Price on capital.
PD	Domestic market prices incl. trade margins.
PDZ	Basic prices of goods on domestic markets.
$PE1,...,PE5$	Prices of oil, electricity, gas, wood and coal, respectively.
PE	Price of energy.
PFU	Price of fuels
PFV	Price of value added
$PIMP$	Import price
PHC	Prices of various categories in private consumption
PK	Private consumption goods
PLF	Price of liquid fuels.
PME	Price of the material-energy composite.
PPK	Private consumption
PQ	Prices of produced goods.
$PSFU$	Price of solid fuels.
PW	Export market price.
Q	Produced goods.
QG	Public consumption.
R	Real rate of return, average level.
SFU	Demand of solid fuels in basic values.

WM Index for export market.
WTU Hourly wages for unskilled labor.
WTS Hourly wages for skilled labor.
WTT Hourly wages for technicians.
WTH Hourly wages for non-technicians.
Z Production activity.

Parameters

ac Capital parameter in production function.
ae Parameter in export function.
afv Value added parameter in production function.
ak Parameter 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.
aq Parameter for domestic production in composite good.
*be*1 Parameter for oil in liquid fuels.
*be*2 Parameter for electricity in energy.
*be*3 Parameter for gas in liquid fuels.
*be*4 Parameter for wood in solid fuels.
*be*5 Parameter for coal in solid fuels.
blf Parameter for liquid fuels in fuels.
bsf Parameter for solid fuels in fuels.
bf Parameter for fuels in energy.
dep Depreciation rate.
*emcoef*1 Coefficients for emissions of CO_2, SO_2 and NO_x in use of oil in industry
*emcoef*3 Coefficients for emissions of CO_2, SO_2 and NO_x in use of gas in industry
*emcoef*4 Coefficients for emissions of CO_2, SO_2 and NO_x in use of wood in industry
*emcoef*5 Coefficients for emissions of CO_2, SO_2 and NO_x in use of coal in industry
emcoefm Coefficients for emissions of CO_2, SO_2 and NO_x in use of materials in industry
*emhcoef*15 Coefficients for emissions of CO_2, SO_2 and NO_x in households'use of gas
*emhcoef*16 Coefficients for emissions of CO_2, SO_2 and NO_x in households'use of fuels
*emhcoef*17 Coefficients for emissions of CO_2, SO_2 and NO_x in households'use of gasoline
*emhcoef*18 Coefficients for emissions of CO_2, SO_2 and NO_x in households' use of bio fuels
hm Trade margin in current prices.

hmk	Trade margin in base-year prices.
$insm$	Input coefficient for materials.
inv	Composition of investment good.
itc	Indirect taxes in consumption.
$itce$	Energy tax in consumption.
$itcSO2$	Sulphur tax in production.
$itcCO2$	Carbon tax in production.
itp	Ad volorem net tax on inputs.
$itpe$	Energy taxes in production.
$itpSO2$	Sulphur taxes in production.
$itpCO2$	Carbon taxes in production.
la	Composition of inventory good.
$metcoef1$	Coefficients for emissions of metals in use of oil in industry
$metcoef3$	Coefficients for emissions of metals in use of gas in industry
$metcoef4$	Coefficients for emissions of metals in useof wood in industry
$metcoef5$	Coefficients for emissions of metals in use of coal in industry
$metcoefm$	Coefficients for emissions of metals in use of materials in industry
$methcoef15$	Coefficients for emissions of metals inhouseholds'use of gas
$methcoef16$	Coefficients for emissions of metals in households'use of fuels
$methcoef17$	Coefficients for emissions of metals in households'use of gasoline
$methcoef18$	Coefficients for emissions of metals inhouseholds' use of bio fuels
$nh3coef$	Coefficients for emissions of nitrohydrogen in agriculture
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.
spk	Elasticity of substitution in consumption.
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 and electricity.
sme	Elasticity of substitution between material and energy.
sz	Elasticity of substitution between value added and the energy-material composite.
tw	labor tax incl. Employer's contribution to social security.
ws	Wage cost distribution, skilled labour.
whk	Wage cost distribution, non-technicians.
wtk	Wage cost distribution, technicians.

wuk Wage cost distribution, unskilled labour.

References

Armington, P.S. [1969] "Adjustments of Trade Balances: Some Experiments with a Model of Trade Among Many Countries",*IMF Staff Paper*, 16. .

Caddy, V. [1976] "Empirical Estimates of the Elasticity of Substitution: A Review", Mimeo, Industries Assistance Commission, Melbourne, Australia. .

Bovenberg, L.A., and Gouldner, L.H. [1996] "Optimal Environmental Taxation in the Presence of Other Taxes: General-Equilibrium Analyses" *The American Economic Review*, Vol. 86, No. 4, pp. 985-1000.

Dixon, P., Parmenter, B.R, Powell, A. and Wilcoxen, P [1992]*Notes and Problems in Applied General Equilibrium Economics*, North-Holland. .

Dixon, P., and Parmenter, B.R [1996] "Computable General Equilibrium Modelling for Policy Analysis and Forecasting" in *Handbook of Computational Economics*, (eds H.M. Amman, D.A. Kendrick and J. Rust), Elsvier.