De Økonomiske Råd

MUSE: Model documentation and applications

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Abstract:
We present a static comparative general equilibrium model for Denmark, MUSE (MUlti SEctor model of the Economic Councils). The model was used in the report of the Danish Environmental Council in Spring 2009 (De Økonomiske Råd, 2009). The model describes 130 production sectors and 11 representative households in Denmark. The presented version of the model focuses on the modelling of green taxes with emphasis on the distributional consequence of alternative green taxes. The main purpose of this paper is to describe the features of the model, but the paper also contains a section that presents some results from the analyses of green taxes.

Keywords: Mathematical Methods and Programming, General Equilibrium, Neoclassical Model, Taxation, Income Distribution, Public Goods.
JEL: C6, D5, E13, E2, H2, H4

Contents

1 Introduction

This paper documents the main features of the static comparative general equilibrium model MUSE (MUlti SEctor model) for the Danish economy. The first version of the model as presented here was developed during 2008 and served as the backbone for generating the empirical results presented in Chapter II on environmental taxes in the report of the Danish Environmental Council in Spring 2009 (De Økonomiske Råd, 2009). Two central analyses in that chapter focused on the dead weight loss from existing environmental taxes, and the welfare costs of reducing green house gas emissions in accordance with Danish national targets.

The central purpose of the project was to develop a flexible model with a core set of economic relationships that would be easily accessible for further development and modification in the future. At the same time the modelling of the consumption and production sides of the economy had to have a level of detail that would facilitate analyses of the economic and certain environmental impacts of changing specific environmental taxes. An additional aim was to make the GAMS computer code easily amendable to changes in assumptions regarding firms' production technology and consumers' ability to substitute between different commodities.[2]

The paper is organised with a description of the model following the introduction. Section 3 guides the reader through the various pieces of data used in the model and section 4 presents selected results from Chapter II of the Danish Environmental Council 2009 report (De Økonomiske Råd, 2009). We finish with some concluding remarks.[3]

Note that the MUSE model is used for agricultural analyses in Chapter I of the Danish Environmental Council 2010 report. This working paper documents the 2009 version of the model and not the further developed 2010 version.

[2] MUSE is modelled in GAMS (The General Algebraic Modeling System). See i.e. Rosenthal, 2008.

[3] Development and the subsequent use of MUSE would not have been possible within this relatively short time frame without the help of and advice from a number of persons. Many people within the staff of the Secretariat of the Danish Economic Councils spent time discussing the features and results of the model. Jesper Jensen (TECA training) was consultant on the model development. Tim Folke from Statistics Denmark answered numerous questions related to the national accounts, tax ("BRAS tables") and air pollutants (NAMEA tables) databases used in the model.

2 The model

2.1 Theoretical background

MUSE is a neoclassical comparative static computable general equilibrium (CGE) model in the Arrow-Debreu tradition.[4] All behavioural relationships in the model are derived from solutions to the economic agents' maximisation problem. In equilibrium, demand equals supply in all markets. The model is static in the sense that the underlying assumption is that a solution to the model represents a characterisation of a long-run equilibrium. It follows in the tradition of the model GESMEC previous used in the Secretariat of the Danish Economic Council; see Frandsen et al. (1995).

Firms produce commodities using capital, labour and intermediates as inputs with a constant return to scale technology. The optimal composition of inputs and the production level are determined by profit maximisation and depend on the technology that firms are assumed to use and relative prices.

Similarly, the consumers maximise their utility derived from commodity consumption and the consumption of leisure based on relative prices of commodities (including labour hired by firms). Consumers own the capital stock which they rent out to the firms. Their consumption of commodities and leisure is constrained by the return to their capital stock and their labour market earnings (subject to a physical constraint on the sum of leisure consumed and labour supplied). All agents are myopic optimisers taking prices as given when they make decisions. To solve the model, assumptions are made regarding firms' production functions and consumers' utility functions.

MUSE describes a small open economy where world market prices are fixed. There are options for having complete international capital mobility (the rental price paid by firms for capital equals the world capital rental price) and complete international labour mobility, in which case wages are given by world prices. Perfect international mobility of capital but no mobility of labour is assumed in the analyses on green taxes. This implies an exogenous interest rate given by the international capital markets. Firms sell part of their output on the domestic market and a part is exported. The export share is determined by the price in the world market relative to the price in the domestic market via an Armington specification (Armington, 1969). This implies that commodities destined

[4] See Shoven and Whalley (1992), Petersen (1997), and Pedersen (2001) for an introduction to CGE models. Also, see Lofgren *et al*. (2002) for a model similar to MUSE.

for export and for domestic use are imperfect substitutes. An analogous specification is made for imported and domestically produced commodities. This is a relatively standard assumption in CGE models, which takes account of the fact that many countries – including Denmark – both export and import the same commodity, even when looking at quite disaggregated levels. The Armington elasticities determine the level of imperfect substitution for each commodity.

The model contains a public sector (or government). The government collects taxes and transfers (both of which may be negative) from firms and consumers, and uses the revenue as remuneration for production factors for production of a public good, which are ultimately consumed. Several taxes are modelled, e.g. taxes on labour income, taxes on capital income, indirect taxes etc. In a standard setup government consumption and production are fixed in real terms and one or more taxes are endogenously scaled to ensure that the government budget constraint is satisfied given the assumptions about the budget balance.

There are several options pertaining to how the initial government budget balance and the current account are treated. For instance, a government budget surplus can be fixed in real terms or as a percentage of GDP.

One salient feature of the model is the detailed modelling of air pollutants. Based on Statistics Denmark's NAMEA-tables (Pedersen, 2003), 8 of the most important air pollutants (CO_2, CH_4, N_2O, NH_3, NMVOC, SO_2, NO_x, CO) are modelled at the model's most disaggregated level of 130 producing sectors and 70 consumer goods. Emission levels of each air pollutant for each producing industry are linked to the level of each intermediate good (130 different intermediates for each industry at the most disaggregated level, i.e. 130 x 130 emission coefficients for each type of pollution) and the output level for the given industry. Similarly, emission levels are linked to each of the 70 consumer goods (at the most disaggregated level).

As an example take the emission of CO_2 equivalents. The level of emissions of CO_2 equivalents for each industry is linked to the use of intermediates with a carbon content which is released in the production process (i.e. petrol, coal, oil and natural gas) and for a few industries (notably agriculture) to the level of output. Consumers' emissions of CO_2 equivalents are based on their consumption of consumer goods with a carbon content being released in the process of consumption (again, petrol and natural gas being prime examples).

Emission coefficients can be static – as would seem natural for CO_2 emissions from carbon fuels – or they can be changed i.e. as part of a policy scenario that changes agricultural production processes and thereby limits the emission of N_20 for each unit of output produced.

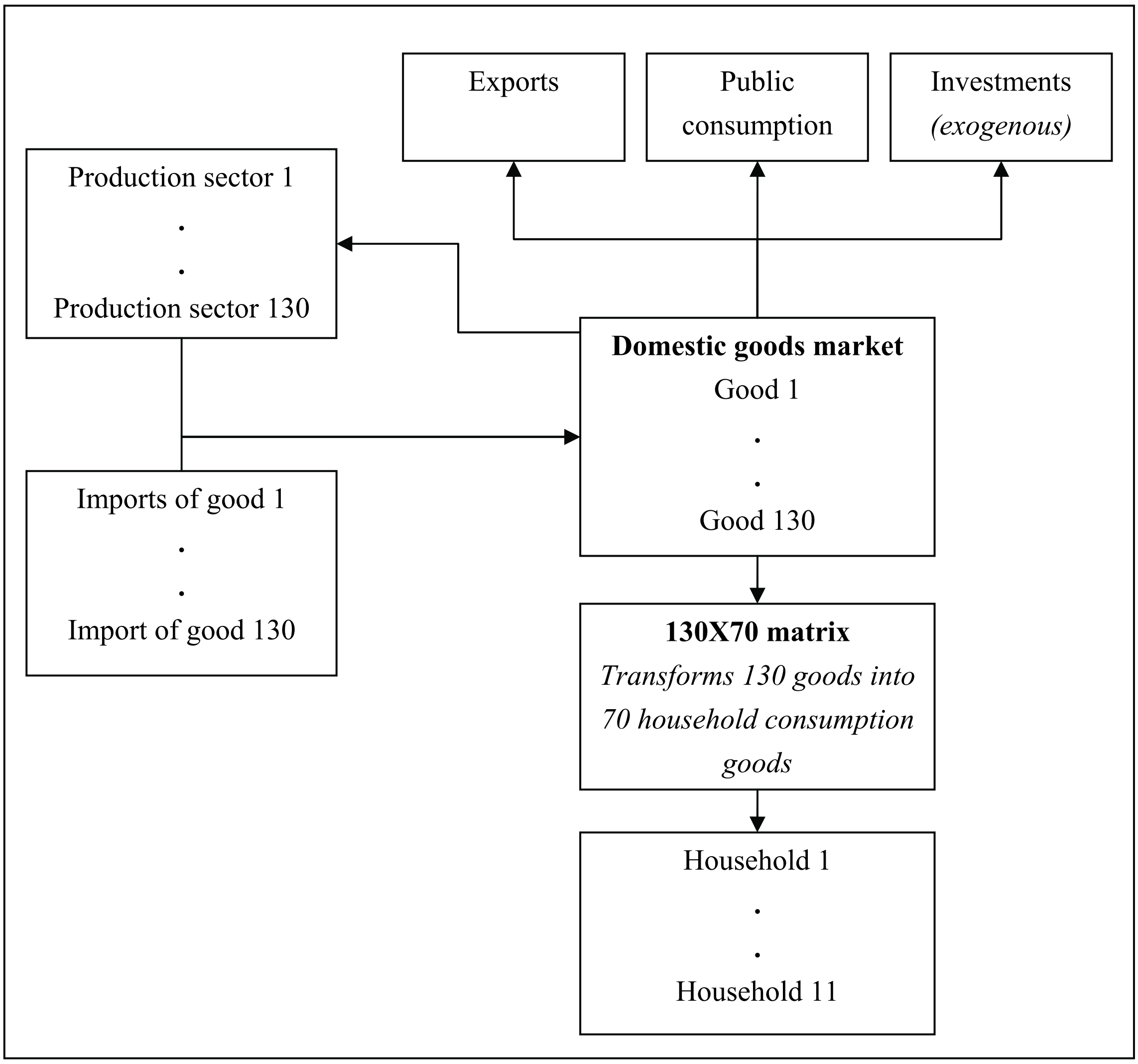
The model is built around input-output data supplied by Statistics Denmark and it is consistent with the Danish National Accounts. The input-output data are supplemented by detailed tax statistics (the "BRAS-tables" that link indirect taxes to cells in the IO matrices) and statistics covering air pollutants both of which are consistent with the input-output data.

2.2 Overview of the model

This section gives the flavour of the modelling approach.

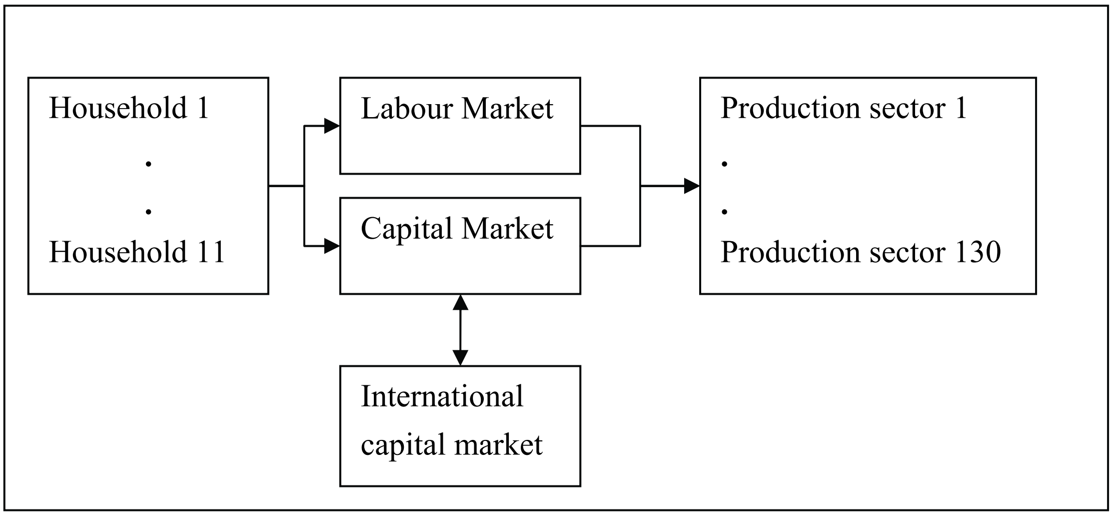
MUSE contains four types of economic agents; households, production sectors, a public sector and the outside world. Figures 1 and 2 give an overview of the interactions between the economic agents in the commodity markets and the factor markets.

Figure 1 Overview of the commodity markets in MUSE



Note: Also exports, public consumption and investments takes place at a 130 commodity level.

Figure 2 Overview of the factor markets in MUSE



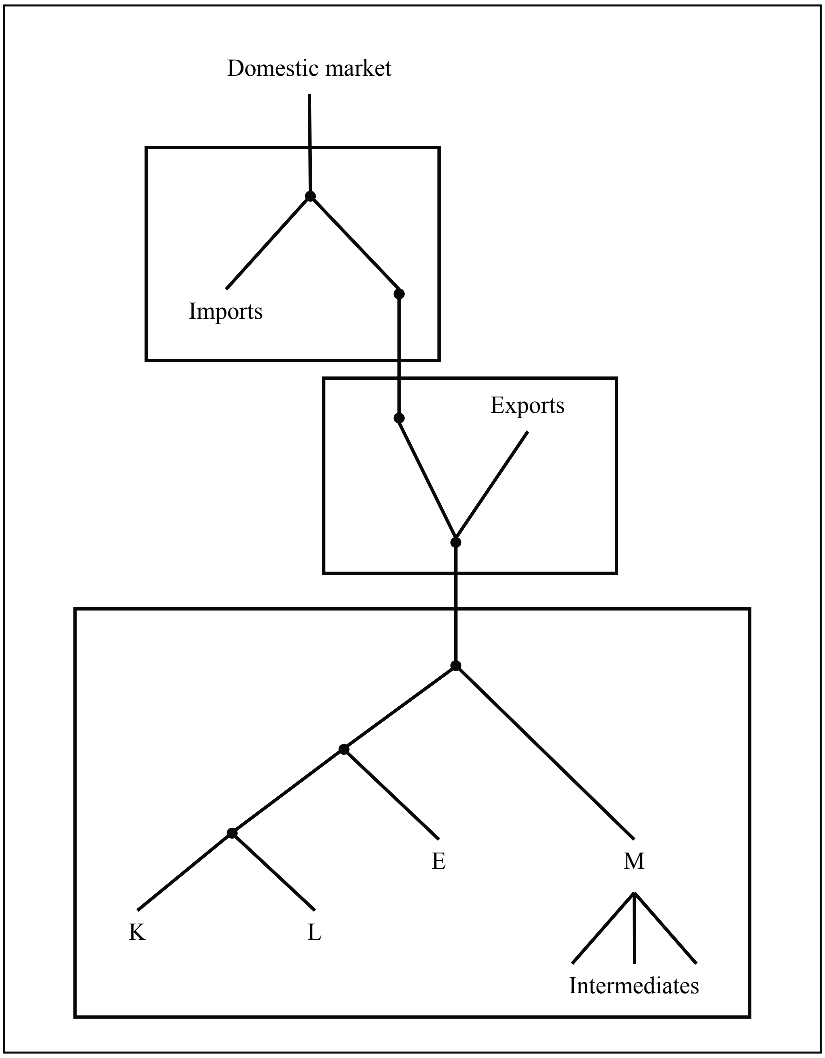
Both agents and markets are described in more detail below.

Production sectors

MUSE contains 130 production sectors that minimize costs subject to their production level. All production sectors exhibit constant returns to scale such that marginal productions costs equal average production costs. This is done with a constant elasticity of substitution (CES) technology. The production functions are modelled as nested CES functions. The bottom part of Figure 3 shows an example of a KLEM production function where the substitution of *K* and *L* (capital and labour) takes place at the first level (for more on this see the section Data). At the second level an aggregate of *K* and *L* is substituted against *E* (energy) and finally an aggregate of *KLE* is substituted against *M*. *M* is an aggregate of intermediates. This produces the output of the particular production sector. The nesting structure is, however, fully flexible and can easily be changed.

Each sector produces two varieties of their product, one for domestic markets and one for export. The production sectors uses 130 intermediates and two factors, capital and labour, in their production. Perfect competition is assumed in all commodity markets. This implies that production is zero-profit, that is, the total proceeds from the sale of output will, in equilibrium, just cover the total cost of inputs – capital, labour and intermediates.

Figure 3 Modelling of the production structure in MUSE



Households

There are 11 representative households in the model which maximize utility of consumption of 70 consumption commodities and leisure subject to a budget constraint. The budget constraint is based on an initial endowment of time and capital. Time can be used for either leisure or labour supply. Capital can be rented to production firms (also internationally). A fixed amount of household consumption is assumed to be invested. Household utility is "produced" by a series of nested CES utility functions (see figure 4 in the Data section). All households have equal nesting structures except for the top nest where leisure is combined with the consumption goods aggregate. In the top nest the elasticity of substitution between leisure and consumption goods is calibrated individually for each household such that the labour supply elasticity is the same for all households. The number of households is fully flexible – the households may be aggregated or more household may be added.

Public sector

The public sector produces an exogenous amount of public production in either real or nominal terms using CES technology with inputs of capital, labour and intermediates. The public sector receives income from taxation of household and production sectors. The public sector taxes the use of all commodities and factors in the model. These are taxes on commodities used for consumption or for inputs in production, taxes on labour and capital supplied by households, green taxes on emissions and taxes on imports and exports.[5] The public budget is assumed to be balanced at all times. The balance is maintained through one or several endogenous tax rates or transfers to households.

The rest of the world

International trade in 130 commodities is possible. Figure 1 and the top part of figure 3 illustrate how trade is incorporated into the model. For domestic producers the supply decision regarding the domestic market and exports is governed by an Armington specification. Similarly, the input entering the domestic market (as intermediate or as part of a consumer good) consists of a domestically produced part and an imported part. This is also controlled by an Armington specification, cf. below. The balance of payments is balanced at all times, corresponding to the base year balance of payments. This balance is ensured by endogenous terms of trade.

Commodity markets

In equilibrium prices and quantities are adjusted such that supply equals demand for the 130 commodities produced. Each of the 130 sectors supplies one of the 130 commodities. The domestic supply and imports comprise the total supply. Each of the 130 sectors demands each of the 130 commodities for inputs in production (several cells are, however, empty in the IO-dataset). The public sector demands the commodities for public consumption and the commodities are exported. Households demand the 130 commodities for consumption and investment.[6]

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[5] Taxes can be either positive or negative. A negative tax is a subsidy.

[6] The 130 commodities are transformed into the 70 consumption commodities to reflect the aggregation of the available IO-tables. It is assumed that the 70 consumption commodities include fixed shares of the 130 commodities.

Labour market
The 130 production sectors demand labour for their production depending on the level of production and the price of labour. Labour is supplied by households as a result of their choice between consumption and leisure. In the present version labour is not internationally mobile.

Capital market
The 130 production sectors demand a single type of capital as input in their production process depending on the level of production and the price of capital. An exogenous amount of capital is supplied by households corresponding to the base year level of capital used by the production sectors. Capital can furthermore be imported or exported. It is assumed the there is perfect substitution between capital supplied by households and imported capital (perfect capital mobility).

Imperfections in international trade
An Armington specification is included both in imports and exports. There is an imperfect substitution between domestically produced commodities and the corresponding imported version of the commodity. This is the import Armington. Furthermore, there is imperfect substitution in the domestic firms' production of commodities for domestic markets and for export (the export Armington).

Emissions
Eight types of air emissions are included. The emissions come from the use of inputs in production or from commodities consumed by households or the public sector. There is a fixed emission coefficient linking the use of a specific commodity used for a specific purpose and the resulting emission.

Modelling technicalities
The model is based on the MCP (mixed complementarity) approach. This implies that all equations can be treated as inequalities. Using the Kuhn-Tucker approach to solve for the first order conditions, a set of inequalities that are all assigned a complementary slack variable is created; see e.g. Sydsæter (1987). The slack variable is the shadow value of the equation. If the equation holds with strict equality, the slack variable has a positive value. If the equation holds with strict inequality, the slack variable equals zero.

One advantage of this approach is that it makes it possible to specify inequalities. This can be convenient e.g. with constraints on emissions that can be either binding or non-binding. Another advantage is that it is possible to use the shadow value of an equation explicitly in other parts of the model. With, e.g., tradable emission quotas, the shadow value of the equation specifying the emission constraint equals the quota price. The value of the quotas (i.e. the quota price times the number of quotas) should be transferred from the buyers of the quotas to the sellers. In the specification of this it is convenient to be able to use the shadow value of the emissions constraint explicitly.

All first order conditions are specified as calibrated share form equations.[7] This makes the calibration of the model very easy and the interpretation of the equations straight forward.

[7] See e.g. http://www.gams.com/solvers/mpsge/cesfun.htm for an overview of calibrated share form equations.

3 Data

3.1 Input-output tables for 2005

The core data source for the model is the 2005 input-output tables published by Statistics Denmark. At the most disaggregated level these tables contain information on the production structure of the Danish economy divided into 130 production sectors. They also cover public consumption of intermediates from the 130 production sectors and private consumption of 70 end-use consumption goods produced by the production sectors.[8] In addition, total taxes (product taxes and VAT) levied on each producing sector and on each of the consumption goods are included. The 2005 input-output tables are described in detail in the publication 'Danish Input-Output Tables and Analysis 2007' (Statistics Denmark, 2007).

3.2 Households

3.2.1 Consumption

To assess the distributional impact of changing the tax structure, MUSE has 11 different representative households. These are made up of one representative household for each income decile of households with at least one household member in the labour force. Household income is measured on a per adult basis. The 11th household represents households where all adult household members are outside the labour force.

The input-output tables contain information on what can effectively be thought of as one aggregate household. Thus, additional work had to be done in order to disaggregate the aggregate information on household consumption and taxes. To this end a representative household survey for 2005 ('Forbrugsundersøgelsen 2005') – covering approximately 2,400 households – with detailed consumption data for a large number of commodities was combined with information on income from administrative records for the entire Danish population of households.[9]

First the data on the full population was used to establish income brackets for the 10 income deciles of households with at least one member in the labour force. Then each of the households interviewed in the detailed household survey was assigned either to an

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[8] Input-output tables from various years are downloadable from Statistics Denmark's homepage: www.dst.dk

[9] For more information on the household survey see Statistics Denmark (1999).

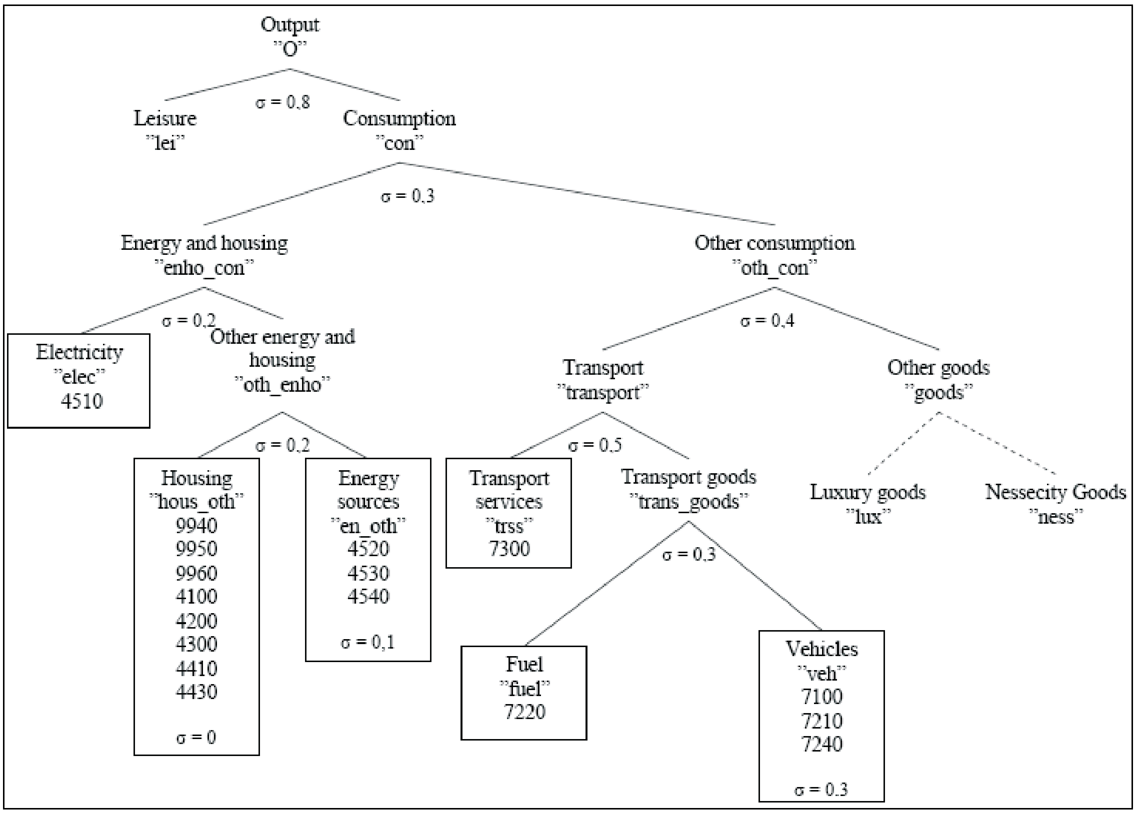
income decile based on its total income or – in the case where all adult members were outside the labour force – to the group of households outside the labour force. After assigning all of the approximately 2,400 households to one of the 11 representative households, we aggregated the consumption data in the household survey for each household to make it consistent with the commodity groupings in the input-output tables. This involved aggregating the 1000+ commodities covered by the household survey into the 70 commodity groups present in the input-output tables.[10] For each of the 11 representative households the share of total consumption of a given commodity group is then calculated based on average household consumption, and adjusted by a factor reflecting that the 11th representative household represents a larger share of the population of households than the 10 households representing income deciles.

The next step was to allocate private consumption of the 70 commodity groups in the input-output table to each of the 11 representative households. This was done using the consumption shares described above. This procedure ensures that information from the best source of detailed consumption data (the household survey) is incorporated in the model, while at the same time, consistency with the national accounts and input-output tables is maintained.

The procedure described above establishes a benchmark data set for consumption of commodities for each of the 11 households. To complete the modelling of household consumption, assumptions about the substitutability of different groups of commodities had to be made. This involved specifying a structure describing consumption decisions and behaviour in the case of changes in relative prices (i.e. in the face of a policy scenario). The present version of the model has a CES utility structure where leisure and an aggregate consumption bundle are substitutes in the top nest. The aggregate consumption bundle consists of a fairly involved set of CES nests, cf. figures 4 and 5. The household consumption structure was built following the recommendation of Shoven and Whalley (1992) to bundle commodities which are close substitutes together. Elasticities of substitution were then chosen and adjusted such that the implicit price elasticities were within reasonable ranges.

[10] See Statistics Denmark (1999).

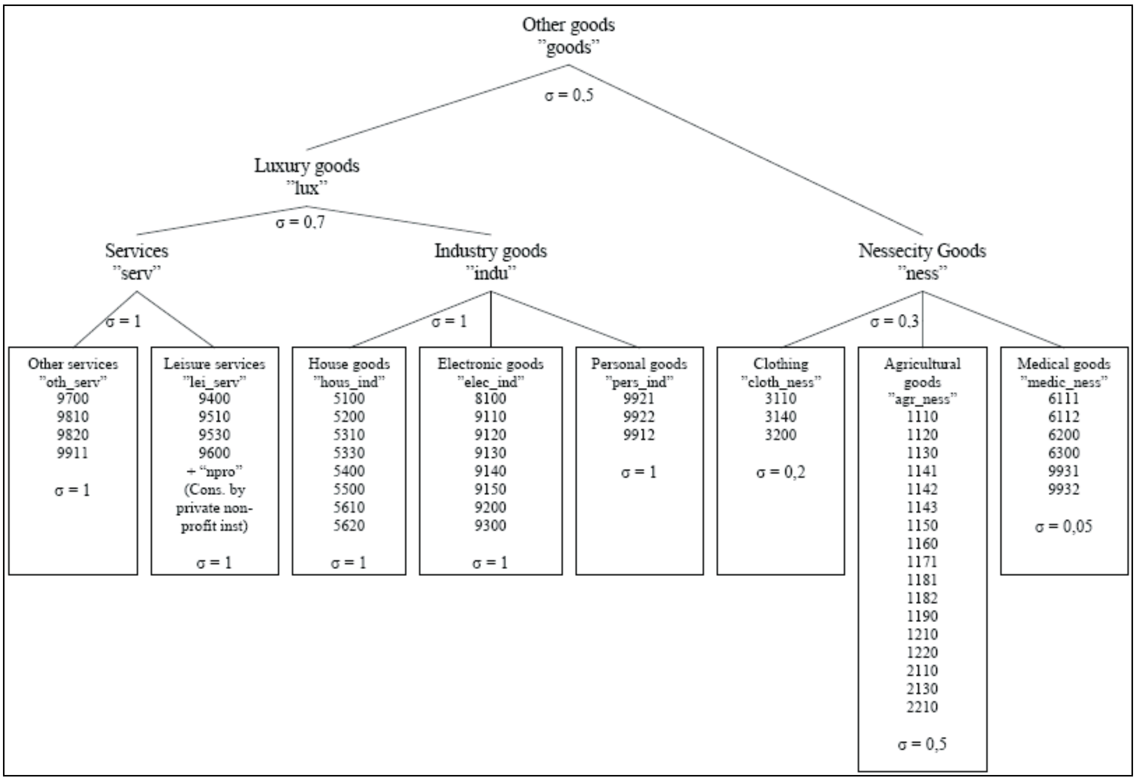
Figure 4 Structure of household consumption



Note: Sigma (σ) is the assumed elasticity of substitution. The numbers in boxes refer to the commodity numbering in the national accounts.

'Other consumption' consists of transport goods and other goods, which is again a composite of 'luxury goods' and 'necessity goods'. The composition of these two bundles is shown in figure 5.

Figure 5 Structure of household consumption



Note: Sigma (σ) is the assumed elasticity of substitution. The numbers in boxes refer to the commodity numbering in the national accounts.

3.2.2 Income, income taxes and transfers

The section above described the procedure for allocating consumption from the input-output tables to the 11 representative households in a consistent manner. A similar problem is encountered with the allocation of labour and capital income. The input-output tables contain information about total remuneration of labour and capital (which is assumed to be directly and indirectly owned by households). To allocate these amounts to the representative households we used the household survey to find average total wage earnings and total capital income for each of the 11 groups of representative households. Again, an adjustment was made to reflect the fact that the group of households with adults outside the labour market only, represents a larger share of Danish households than each of the 10 income decile representative households.

The income tax system is modelled separately for labour and capital income. This greatly simplifies the modelling of the income tax system at the cost of some loss of analogy to the income system existing in Denmark. However, taxation of capital income in Denmark remains rather complicated with different tax rates depending on, e.g., the source of the income and ones level of labour income, see De Økonomiske Råd (2008).

While the capital income tax is modelled as a simple flat tax set at a level comparable to the average rate with which capital income was taxed in 2005, the system of labour taxes is more elaborate. Because the emphasis in the analyses is on the effect of changes in environmental taxes on the income distribution and labour supply, the labour income tax system is progressive with three different tax rates applying to different labour income levels. This broadly reflects the marginal tax rates that wage earners in Denmark face depending on their level of income. The tax system is implemented such that a household – as a result of a policy scenario – can shift between two marginal tax rates, if its income changes such that it falls into an income bracket different from its benchmark income bracket.

Tax rates for different income brackets can be set to equal actual tax rates in place in Denmark. However, with 11 representative households sharing total labour and capital income, real world actual income brackets for taxation purposes are not useful. Instead we manually calibrated the income brackets such that the total revenue from the top and middle income tax rates matched those collected for these taxes in 2005. Clearly, these steps, which determine the households' consumption and income, are unlikely to make each of the 11 households' budget constraints hold with equality as must be the case with a CES utility function. Some of the representative households may spend more than their income net of taxes while others spend less. The difference between net income and total spending on consumption for each household is closed by a lump-sum transfer from the government. For all 11 households the lump-sum transfer was positive. It can be interpreted as a crude way of modelling the earned income tax, tax deductions and various other income transfers in place. By definition the government budget constraint will also hold with equality; total income generation equals total end-use consumption. Since, government and household consumption adds to total consumption, and government and household income adds to total income, ensuring that the households' budget constraints are satisfied will make certain that the government's budget constraint is also satisfied.[11]

3.3 Production

[11] There is a corollary to this: In 2005 the total value added in Denmark was larger than total income generated (Denmark ran a current account surplus). In addition, there are inventory changes and production for investment purposes. All of these can be thought of as saving, which is not modelled in the present version of the model. Hence, in fact, total consumption was lower than total income generated. This was dealt with by scaling the lump-sum transfers such that the budget for households was balanced.

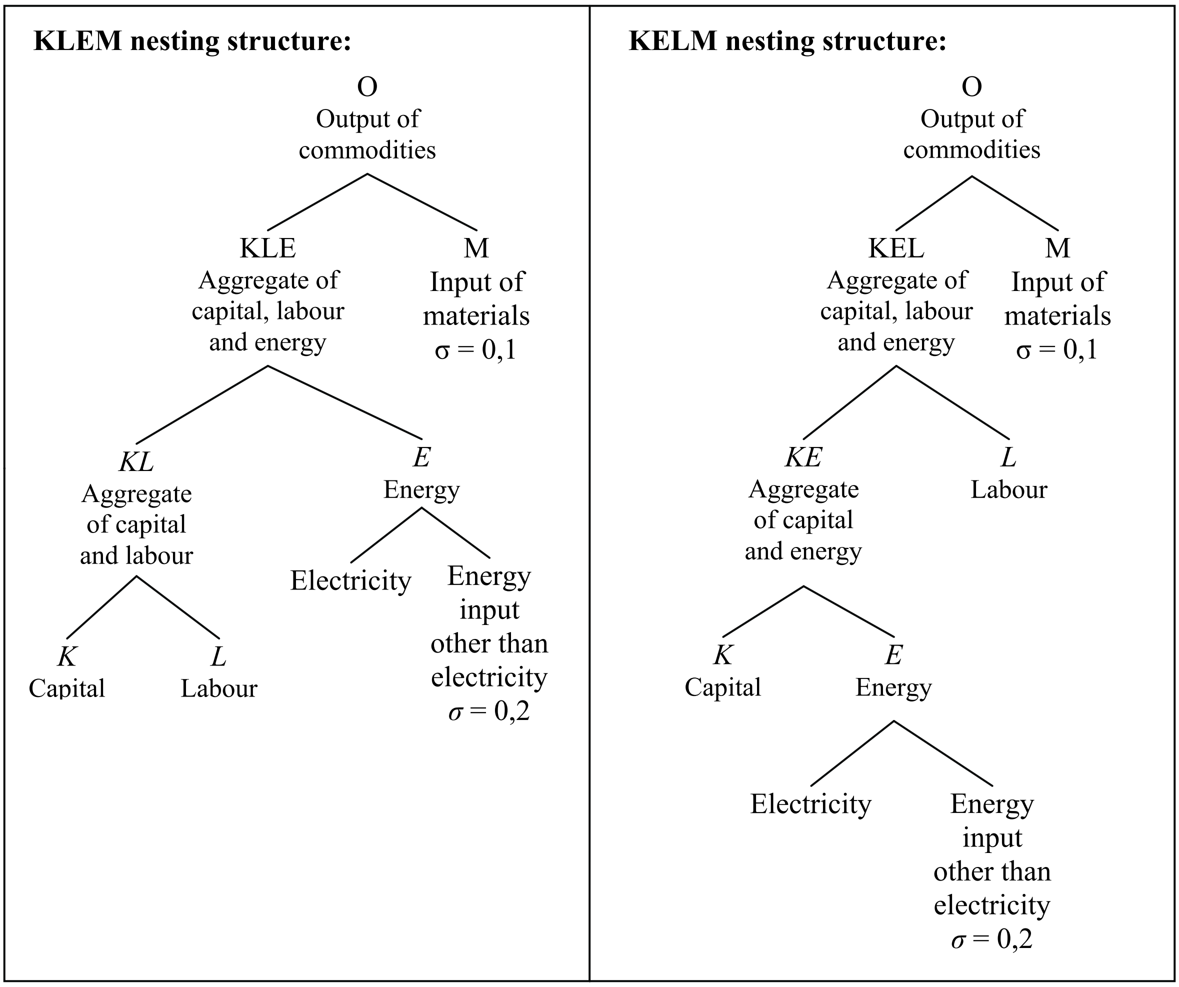
At the most detailed level MUSE consists of 130 producing sectors. They deliver intermediates to 130 sectors (including themselves) and components of the 70 consumer goods. Each sector use intermediates – not necessarily from all other sectors – capital and labour. For each of the 130 sectors the input-output tables list the detailed amount of inputs. Thus, benchmark levels are directly available from the input-output tables.

One problem arising is that in any given year there are likely to be one or more sectors with a negative return to capital. This conflicts with the assumption that the return to capital is equal across all sectors (and, in the case of international capital mobility, equal to a world market interest rate). We dealt with this issue by looking at the average return to capital in these sectors available from input-output tables over the last 10 years. Then the difference between the 10-year average return and the negative return in 2005 was subtracted from the cell for labour earnings and added to the cell for capital earnings. This kept the total pay to production factors for the given sector unaltered.

The production structure, i.e. how different inputs substitute for each other, is of particular importance when analysing the effect of production taxes on industries' CO_2 emissions. Therefore, the project paid special attention to this. Price elasticities – and implicitly elasticities of substitution – were estimated on time series data for 19 aggregate sectors and then used on each sector making up each of the 19 aggregate sectors (Thomsen, 2008). These 19 production sectors are equivalent to the ones used in the macroeconomic model ADAM (Statistics Denmark, 1995).

The econometric procedure used for estimation considered 4 main input aggregates: labour (*L*), capital (*K*), energy (*E*) and material (*M*). The energy bundle consists of intermediates from the production of electricity, gas, steam and hot water supply, refined petroleum products as well as extraction of crude petroleum and natural gas. The materials aggregate is an aggregate of all other intermediates which are not in the energy bundle. For each of the 19 sectors, two nesting structures were considered; KLEM and KELM; cf. figure 6. A KLEM nesting structure has capital and labour substituting at the lowest level. The KL bundle then substitutes with the energy aggregate. Finally, the KLE aggregate substitutes with the materials aggregate. The KELM structure differs in that energy and labour enter the production function in a different order.

Figure 6 The KELM and KLEM nesting structures



Which nesting structure fitted the data the best was tested econometrically and that nesting structure together with elasticities of substitution were modelled accordingly. Elasticities of substitution and the nesting structure for each of the 19 aggregate sectors are presented in table 1.

Table 1 Estimated elasticities of substitution for 19 ADAM sectors

Sector	KLEM or KELM?	---------- Elasticities of substitution ----------					
		KL	KE	KLE	KEL	KLEM	KELM
Inputs in construction	KLEM	0,51	-	0,13	-	0,79	-
Chemical industry	KLEM	0,25	-	0,56	-	0,89	-
Iron and metal industry	KLEM	0,34	-	0,24	-	0,59	-
Other manufacturing	KLEM	0,38	-	0,45	-	0,86	-
Production of transportation	KLEM	0,43	-	0,43	-	0,77	-
Other services	KLEM	0	-	0,06	-	0,83	-
Public services	KLEM	0	-	0,06	-	0,83	-
Housing	KLEM	0	-	0,06	-	0,83	-
Electricity, gas and dis-trict heating	KLEM	0,45	-	0,45	-	0,38	-
Coal, oil and natural gas	KLEM	0,45	-	0,45	-	0,38	-
Refinement of oil	KLEM	0,45	-	0,45	-	0,38	-
Agriculture etc.	KELM	-	0,08	-	0,23	-	0,77
Construction	KELM	-	0,06	-	0,04	-	1,18
Foodstuff industry	KELM	-	0,15	-	0,03	-	0,56
Stimulants industry	KELM	-	0,04	-	0,64	-	0,62
Trade	KELM	-	0,14	-	0,07	-	1,22
Financial services	KELM	-	0,45	-	0,06	-	1,04
Transport except sea transport	KELM	-	0,16	-	0,06	-	0
Sea transport	KELM	-	0,16	-	0,06	-	0

Source: Thomsen (2008) and own calculations.

The nesting structures for the energy and materials aggregates were modelled with an eye to the structure used in EMMA – an energy model to use with ADAM (Statistics Denmark, National Environmental Resource Institute and RISØ, 1997 and Statistics Denmark and RISØ, 2007).

3.3.1 Product taxes

Many environmental taxes – and taxes to reduce CO_2 emissions in particular – are levied on final consumption of consumer goods and on intermediates in production of these consumer goods. Therefore it is essential to keep track of which taxes are levied where. This information is not available in traditional input-output tables. To make sure taxes were applied correctly we relied on detailed statistics (the "BRAS"-tables) obtained from Statistics Denmark with recordings stating for each indirect tax the amount paid for each corresponding entry in the input-output table. This in effect gave us a 130 by 130 matrix with payments for each indirect tax on intermediates (most entries being zero), and a 70 by 1 matrix for each indirect tax applied to final consumption.[12]

The BRAS statistics are consistent with the national accounts and the input-output tables. Thus, the sum of product taxes paid equals total taxes in the input-output tables. However, a few taxes, mostly subsidies, on some products cannot be assigned to a particular consuming entity. An example is part of the subsidies for train transport. This means that product taxes paid by a given sector do not necessarily sum to the total tax outlay by that sector in the input-output tables. To solve this, a tax equal to the residual difference was levied as an output tax on each specific sector.

The NAMEA-matrices contain data on emissions from all sectors' use of different fuel types. Furthermore, the matrices contain data on households' emissions from consumption of the same fuels for different purposes. Since the modelling of the production function implies that the sectors use inputs from other sectors rather than specific fuel types, the energy emissions are allocated to the sectors where they are produced. This makes it possible to attach an emission to a given sector's use of output from another given sector. In this way the emissions in the model are attached to the sector's use of inputs.

[12] In fact, the statistic used is even more detailed because it is recorded at a more disaggregated level than the officially published input-output tables. With the help of Statistics Denmark we aggregated it to the level of the published tables (i.e. 130 production activities and 70 consumer goods).

There are three residuals in the NAMEA matrices: An energy residual, a road transport residual and a biomass residual. The energy residual is allocated to all energy commodities whereas the road transport residual is allocated to energy commodities from the sector "Manufacture of refined petroleum products etc" and the biomass residual is allocated to the biomass energy commodities.

There are non-energy related emissions from some sectors such as agriculture. In the model these emissions are attached to the output of the sectors. An increase in the output from a sector will therefore result in a proportional rise in non-energy related emissions.

Emissions of N_2O and CH_4 are converted into CO_2 equivalents according to the conversion factors in the Kyoto protocol. Some emissions – such as CO_2 emissions from biomass – are assumed to be CO_2 neutral according to the Kyoto protocol.

4 Analyses produced for the 2009 report of the Danish Council of Environmental Economics

This section briefly describes two sets of analyses carried out as part of the publication of the 2009 report of the Danish Council of Environmental Economics. A more detailed description is available in the report.[13] The first set of analyses looks at welfare effects and several other aspects of increasing environmental taxes across the board, while the second set of analyses focuses more narrowly on welfare effects of reducing greenhouse gas emissions in line with the international commitments of Denmark.

4.1 Welfare effects and distributional consequences of environmental taxes

The analyses featured an assessment of the welfare loss from increasing green taxes (not counting the possible positive value of an improved environment) with different assumptions about the use of the resulting revenue. The economic consequences of increasing the level of green taxes depend greatly on how the resulting revenue is spent, cf. table 2.[14]

[13] The report is only available in Danish.

[14] Green taxes are a group of taxes whose main purpose is to improve environmental quality, e.g. taxes on gasoline, pulp and paper and carbon dioxide.

Table 2 *Effects of increasing the level of green taxes on households and firms combined with alternative ways to spend the revenue*

	Increase tax free allowance	**Reduce bottom tax rate**
Welfare[a)], bn DKK	-1,5	-0,5
Revenue from green taxes, bn DKK	10,6	11,0
Gross value added, percent	-0,4	-0,2

a) Welfare is defined as equivalent variation, i.e., the amount the consumers would have to get to be just as well off as before the tax reform – without involving the cost or benefits of a changed environmental state.

Source: Own calculations with MUSE.

Government revenue of DKK 5 billion collected by a proportional increase in all green taxes and spent on increasing the personal tax-free allowance implies a socio-economic cost of DKK 1.5 billion – not counting the value of changed environmental conditions. However, the socio-economic cost is reduced by approximately DKK 1 billion if the revenue is spent on reducing the bottom tax rate. The reason is that lowering the bottom tax rate stimulates the labour supply, and thereby economic activity.

It is often believed that higher green taxes increase inequality. One reason is that inequality is often measured as differences in annual income rather than annual consumption. Annual consumption may arguably be a better measure for lifetime income than current income, which can be affected by several temporary factors. From a lifetime perspective it is, therefore, more relevant to measure the distributional consequences of green taxes using differences in annual consumption. High income households (measured by total consumption) pay more in green taxes than low income households and households outside the labour force. This holds for green taxes on transport in particular, while green taxes on water and electricity represent a higher consumption share for low income households, cf. table 3.

Table 3 Green taxes and income distribution

	All green taxes	Electricity	Other energy	Transport[b)]	Water	Other environmental taxes	All green taxes
	Bn DKK.[a)]	--------------- Percent of consumption				----------------	
Outside the labour force	0.30	0.94	1.16	2.58	0.23	0.08	4.99
The labour force							
1st decile	0.31	0.96	1.02	3.01	0.19	0.07	5.24
2nd decile	0.40	0.81	1.14	4.02	0.18	0.07	6.21
3rd decile	0.36	0.81	1.06	3.39	0.18	0.07	5.51
4th decile	0.45	0.76	0.97	4.17	0.17	0.07	6.13
5th decile	0.52	0.78	1.02	4.76	0.18	0.06	6.79
6th decile	0.63	0.70	1.04	5.55	0.17	0.07	7.52
7th decile	0.52	0.75	0.98	4.42	0.17	0.07	6.40
8th decile	0.64	0.69	0.93	5.41	0.16	0.06	7.24
9th decile	0.72	0.74	1.07	5.13	0.16	0.07	7.16
10th decile	0.74	0.64	1.06	4.33	0.14	0.07	6.24

a) The group of persons outside the labour force is bigger than the decile groups. For easier comparison, all green taxes are adjusted so they cover the same number of persons (1pct. of the total population).

b) Gasoline taxes are placed under transport.

Note: The decile groups are based on income.

How the revenue resulting from higher green taxes is spent determines the distributional consequences of higher green taxes. Low income households will gain from higher green taxes if the personal tax-free allowance is increased. The distributional consequences are closer to neutral if the bottom tax rate is reduced instead. However, low income households also gain in this case, cf. table 4. High income households lose in both cases as they have a large consumption of commodities on which green taxes are levied.

Table 4 Distributional effects of increasing the green taxes on households and business combined with different spending of revenues

	Increase tax free allowance	**Reduce bottom tax rate**
	-------------------- Bn DKK	--------------------
Total	-1.5	-0.5
Outside the labour force[a)]	0.5	0.3
Average of 1st and 2nd decile	0.3	0.1
Average of 5th and 6th decile	-0.5	-0.3
Average of 9th and 10th decile	-0.9	-0.2

a) The group of persons outside the labour force is bigger than the decile groups. For easier comparison, all green taxes are adjusted so they cover the same number of persons (1pct. of the total population).

Note: Welfare is defined as equivalent variation, i.e., the amount the consumers would have to get to be just as well of as before the increase in taxes – without involving the cost of a changed environmental state.

Source: Own calculations with MUSE.

The analyses further showed that there are differences in the economic distortion caused by different types of green taxes, cf. table 5. Without taking the value of environmental improvements into account, higher energy taxes or taxes on transport cost 40 per cent of the revenue if combined with an increase in the personal tax-free allowance. Higher taxes on water or waste cost only 20 and 30 per cent of the revenue, respectively. The main purpose of green taxes is to regulate externalities, and they should be introduced following the Pigou-principle. A secondary purpose of the green taxes is to raise public revenue. The overall conclusion is that green taxes levied for the purpose of raising public revenues should be introduced where the distortion is lowest, while distributional concerns can play a role in deciding how the revenue is spent.

Table 5 Welfare change with a revenue increase of 100 mil. DKK in alternative green taxes

	------ Mil. DKK ------
All green taxes	-44
Energy taxes [a)]	-46
Transport taxes [b)]	-49
Environmental taxes [c)]	-34
Natural gas tax	-44
Oil products [d)]	-43
Electricity tax	-39
Water [e)]	-18
Waste	-28

a) Coal etc., electricity, natural gas, some oil products and gasoline.

b) Gas, annual vehicle tax, tax on new vehicles.

c) Paper and cardboard, some retail sale packaging, mining and quarrying, disposable tableware, pesticides, waste, CFC, CO_2, Steam and hot water supply, paper or plastic bags etc., nickel and cadmium batteries, sulphur, chlorinated solvents, waste water, nitrogen, certain growth promoters, PVC foil, PVC and phthalates, accumulators and mineral phosphorous in feed phosphates.

d) Certain oil products.

e) Steam and hot water supply and waste water.

Notes: The revenue is spent on increasing the personal tax free allowance. Welfare is defined as equivalent variation, i.e., the amount the consumers would have to get to be just as well of as before the increase in taxes – without involving the cost or benefits of a changed environmental state.

Source: Own calculations with MUSE.

4.2 Costs of reducing greenhouse gas emissions

The second set of analyses looked at the cost of reducing greenhouse gas emissions by the part of the economy outside the EU's Emission Trading Scheme (ETS). As part of the EU's overall target for greenhouse gas emissions, Denmark has made a commitment to reduce the amount of greenhouse gas emitted by the non-ETS sector by 20 percent in 2020 relative to the level of emissions in 2005. A forecast of the level of greenhouse gas emissions in 2020, assuming unaltered policies, shows that the target is unlikely to be met with the current policy (De Økonomiske Råd, 2009).

MUSE was used to evaluate the cost of reducing emissions by a further 4 million tonnes of CO_2-equivalents by levying a uniform tax on the non-ETS sector's greenhouse gas emissions on top of the existing tax structure.[15] The results showed that to achieve this reduction, a tax of the magnitude of DKK 400 per tonne CO_2-equivalent (2005 prices) is needed. This should be compared with the expected price of a CO_2 quota in the ETS sector of DKK 225 per tonne CO_2. Thus, the calculations indicates that in Denmark the

[15] The remaining part of the required reduction in greenhouse gas emissions are assumed to be accomplished by buying non-ETS quotas in other countries.

marginal cost of reducing greenhouse gas emissions in the non-ETS sector could be close to double the expected marginal cost in the ETS sector.

The results also gave insights into which parts of the economy would bear the burden of a uniform tax on greenhouse gas emissions, cf. table 6.

Table 6 Distribution of green house gas emissions with a reduction of 4 mil. tonnes CO_2 equivalents

	CO_2 equivalents	**Change**	**Reduction**
	- Mil. tonnes -	- Mil. tonnes -	-- Percent --
Households	10.4	0.4	3
Heating	4.0	0.1	2
Transport	6.4	0.3	4
Total of business	25.4	3.6	14
Energy related	13.8	1.3	9
Agriculture	1.3	0.3	26
Other business	12.5	1.0	8
Not energy related	11.6	2.3	21
Agriculture	10.0	2.3	23
Other business	1.6	0.0	2
Total of non quota emissions	35.8	4.0	11

Notes: The resulting revenue is spent by increasing the personal tax free allowance.
Source: Statistics Denmark's NAMEA tables and own calculations

A major part of the reduction (90 per cent) would come from the production side of the economy whereas households – in the form of reduced consumption of heating and transport services – would contribute 10 per cent, which is equivalent to 0.4 million tonnes of CO_2-equivalents. There are two main reasons for this. First, initially households have much larger tax burdens on consumption of transport services and heating, the two culprits of household greenhouse gas emissions, than do industries on their sources of greenhouse gas emissions. A uniform tax on greenhouse gasses therefore translates into smaller changes in relative prices for households' use of greenhouse gas emitting goods than it does for industries use of greenhouse gas emitting intermediates.

Second, substitution away from greenhouse gas emitting consumption is more difficult for households than for industries since the production sector can import energy intensive intermediates instead of having them produced domestically. In the short run this will hurt greenhouse gas intensive industries, however, in the long run with general equilibrium effects having worked their way through the economy, resources previously employed in greenhouse gas intensive industries will be utilised in other less intensive production.

This is particularly true for the agricultural sector. Because of the sector's large non-energy related emissions which are initially untaxed, a uniform tax on greenhouse gas emissions leads to a relatively large increase in the cost of production. At the same time agricultural commodities are relatively close substitutes across borders, meaning that small changes in domestic agricultural output prices lead to comparatively large changes in imports of agricultural products. In the long run the domestic agricultural sector shrinks markedly leading to a large fall in the sector's emission of greenhouse gasses, cf. table 6.[16]

The analyses included an assessment of the macroeconomic effects of a reduction in greenhouse gas emissions of 4 million tonnes CO_2 equivalents. The total welfare cost measured in terms of equivalent variation varies depending on how the resulting revenue from the uniform greenhouse gas tax is used, cf. table 7.

Table 7 Macroeconomic effects of a reduction of 4 mil. CO_2 equivalents

	Tax free allowance	**Bottom tax rate**
Welfare, bn DKK	-2.1	-0.9
Gross value added, percent	-1.7	-1.5
Employment, percent	-0.1	0.1
Revenue for increasing the tax free allowance, bn. DKK	6.2	•
Decrease in bottom tax rate, percentage points	•	0.8
Change in emission of CO_2 equivalents, mil. tonnes	-4.0	-4.0

Notes: Welfare is defined as equivalent variation, i.e., the amount the consumers would have to get to be just as well of as before the increase in taxes – without involving the cost or benefits of a changed environmental state.

Source: Own calculations with MUSE.

If the revenue is returned to the households in a lump-sum fashion, the loss in terms of equivalent variation is DKK 2.1 billion, which is roughly equivalent to 0.15 percent of the Danish GDP. Employment will suffer marginally. Alternatively, the revenue could be used to lower the bottom tax rate by close to one percentage point. The welfare cost

[16] This is, however, partially a result of the modelling that does not include land as a fixed factor. If land was included, the effects on agriculture might be less.

is limited to around DKK 1 billion due to the labour supply effect stemming from the lower tax rate. The general equilibrium effect on employment is a slight increase in employment.

5 Concluding remarks

This document has presented the main features of the Economic Council's MUlti SEctor (MUSE) general equilibrium model. The goal has not been to document every single equation, but instead to highlight the general modelling approach and, in particular, to document the data sources. The information contained herein is not sufficient to duplicate the results presented, however, we hope the document will be a good aid when reading the GAMS-code and in understanding which data sources went into the model.

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