Energy Policy and Carbon Emission in Russia: A Short Run CGE Analysis

Anton Orlov, Harald Grethe, Scott McDonald

Abstract

In this study we investigate the economic effects of carbon taxes on the Russian economy. The main findings of this study are the following: an introduction of carbon taxes compensated by an increase *in lump-sum subsidies* may weak the Russian economy through higher energy costs. Moreover, such an environmental tax reform could induce Dutch disease in Russia because of increases in the domestic production of crude oil. Exports of crude oil, petroleum products, natural gas, and minerals increases, thereby increasing revenues from export taxes, whereas revenues from all other taxes decrease. In contrast, an introduction of carbon taxes compensated by a *reduction of taxes on labour* results in an increase in domestic production of most non-energy producing sectors, which implies increases in real GDP and household expenditures. The shift in the economic structure towards non-energy producing sectors is more pronounced under carbon taxation which is compensated by a reduction in labour taxes. Moreover, such an environmental tax reform can induce a double dividend. However, the results strongly depend on the labour supply elasticity as well as elasticities of substitution between labour and the capital-energy aggregate. For instance, a higher labour supply elasticity implies a lower increase in labour costs. Moreover, higher elasticities of substitution between labour and the capital-energy aggregate encourage a shift of the tax burden from labour to capital. Finally, carbon taxation in Russia may induce a strong carbon leakage in other countries due, in particular, to a strong increase in the export supply of natural gas and petroleum products.

JEL classification code: Q40, Q50, C68

Key words: energy efficiency, double dividend, carbon taxes, Russia

Anton Orlov,
Department of Agriculture and Food Policy (420a),
University of Hohenheim,
Schloß, Osthof-Süd.
70599 Stuttgart.
Email: orlov@uni-hohenheim.de
Tel: 0711 459-22522
Fax: 0711 459-23752

Harald Grethe,
Department of Agriculture and Food Policy (420a),
University of Hohenheim,
Schloß, Osthof-Süd.
70599 Stuttgart.
Email: grethe@uni-hohenheim.de
Tel: 0711 459-22631
Fax: 0711 459-23752

Scott McDonald,
Department of Economics,
Oxford Brookes University,
Wheatley Campus.
Oxford, OX33 1HX, UK.
Email: smcdonald@brookes.ac.uk
Tel: +44 1865 485948

Contents

1 Introduction

Russia is not only one of the world's major sources of carbon based energy – coal, oil and gas - but is also one the most intensive users of energy. Furthermore, Russia accounts for a disproportionately large share of global carbon emissions – some 5 to 7 percent of global carbon emission (EIA, 2008); even after making allowance for climatic conditions. In large part the high carbon emission rates are a consequence of outdated and inefficient technologies, a legacy of the Soviet era, reinforced by the low cost of energy. The major source of these emissions is the power generation sector (Bashmakov, 2009), which has the greatest potential technological energy saving, but the residential building, manufacturing, and transport sectors also have substantial scope for improved energy efficiency. It has been estimated (World Bank, 2008) that Russia could reduce its use of primary energy use by some 45 percent, with consequent economic and environmental benefits.

However energy using technologies are typically embedded in capital equipment, e.g., power stations, smelters, etc., and buildings, which have potentially long productive lives, and hence the pace of technological change is inevitably a costly and long process. There are different barriers, which can slow down technical modernization. Generally, two explanations for a slow technological diffusion can be distinguished. The first explanation is non-market failures, such as the underestimation of adoption costs, high discount rates, and heterogeneity of energy users. The second explanation is market failures, such as lack of information and low energy prices from non-internalised environmental externalities or inefficient price regulation. In addition, there are also positive externalities from the introduction of less energy intensive technologies such as "learning by doing". Nevertheless, market failures provide justifications for government intervention only (Jaffe, 2004).

Crudely government intervention could be exercised by legislated restrictions on emissions or by market interventions designed to internalise negative environmental externalities and thereby reduce emissions. Carbon taxes are one such Pigovian tax. In this context carbon taxes would, potentially, address the concerns on several fronts simultaneously. In the short to medium terms they would, *inter alia*, (1) reduce the emission of CO2 and other emissions such CH_4, N_2O, SF_6, and SO_2, which are stemming from the use of energy commodities, induce energy users to (2) optimize the use of existing plant, (3) substitute lower emission energy source for higher emission sources and (4) adopt passive energy saving technologies, e.g., improved insulation. In the longer term the increased cost of primary energy products should both accelerate the rate of technological replacement and induce technological progress (Ruttan, 1997; Newell et al. 1999). Recent evidence (Popp, 2002) indicates that there is a significant relationship between energy prices and new innovation in energy-saving technologies. In addition, a reduction in carbon emission will provide carbon credits, which can be sold in the international markets. Furthermore, according to the environmental taxation literature, introducing carbon taxes compensated by a reduction in other distortionary taxes may lead to a double dividend, where the environmental tax reform can induce not environmental welfare gains only, but can also reduce efficiency costs of the tax system.

The objective of this study is to analyse the sectoral and macroeconomic impact of carbon taxes on the Russian economy and to verify the hypothesis of double dividend. This analysis is based on a computable general equilibrium model – an energy/environment adaptation of the STAGE model (McDonald, 2007). To our knowledge this is the first such study for Russia. The rest of the paper is organised as follows. The next section gives a brief introduction into the concept of double dividend. Section three provides a brief description of the model – more details are provided in a technical appendix. Section four reports on the database used to calibrate the model and provides some descriptive statistics about the base case. Section five gives an overview of experiments and the sensitivity analyses. The results of the simulations, described in section six, are presented in two sections; section six reports the main results while section seven reports the sensitivity analyses. A summary of the main results and the sensitivity analyses is given in section eight. The final section provides a discussion of the implications together with comments on how the analyses can be further developed. The main findings of this analysis is that introducing carbon taxes compensated in a reduction of labour taxes can yield a double dividend in Russia; however, this strongly depends on the labour supply elasticity and elasticities of substitution between labour and capital-energy aggregate.

2 Double Dividend Hypothesis

While carbon taxes will increase production costs, the environmental taxation literature argues the case for a double dividend. The relatively uncontroversial "weak" double dividend hypothesis argues that, using revenues from environmental taxes to reduce other distortionary taxes, one can achieve cost savings (reductions in welfare costs of taxation) compared to the case where revenues are returned to households in lump-sum form. On the other hand, the more ambiguous "strong" double dividend hypothesis argues that not only can welfare from an environmental improvement be increased but that they can further enhance national welfare gains by alleviating pre-existing distortions (Goulder, 1994).

From a theoretical point-of-view, the double dividend may be feasible in the presence of pre-existing distortionary taxes if environmental taxes induce a strong tax-shifting effect which overweighs the tax-burden effect. In particular, there are three main types of tax-shifting effects that may lead to a double dividend: tax-shifting among factors, tax-shifting across countries, and tax-shifting among household incomes (Mooij, 1996). Therefore, a shift of the tax burden from an over-taxed factor to an under-taxed factor can induce environmental and economical improvements (Bovenberg and Goulder, 1996a). However, the effects of an environmental tax reform may crucially depend on factor mobility. Mooij and Bovenberg (1996) and Bovenberg and Ploeg (1998) write that a shift of the tax burden from mobile labour towards immobile capital may lead to a double dividend; however, in the long-run, capital is rather mobile. Therefore, the environmental tax reform could exacerbate rather than alleviate initial inefficiencies in the tax system. Apart from capital, natural resources can also be considerated a fixed factor. For instance, Bento and Jacobsen (2007) show that in the presence of a fixed factor (natural resources) and Ricardian rents, an environmental tax reform may induce a double dividend since environmental taxes would partially fall on natural resources. Furthermore, Carraro and Soubeyran (1996)'s empirical model emphasises that under a second-best setting, an occurrence of an employment double dividend may be possible, yet they find that welfare gains of an environmental tax reform mostly depends on the initial tax system. Moreover, a study carried out by Bosquet (2000), which reviewed 139 modelling simulations, shows that under certain conditions an introduction of environmental taxes may achieve both environmental and economic improvements, especially if revenues from environment taxes are recycled trough a reduction of social security contributions. Generally, the occurrence of double-dividend effects is not unambiguous. The outcome depends basically on the tax and economic structure, household preferences, factor mobility, factor substitutions, and revenue recycling strategies. Hence general equilibrium analysis is an appropriate analytical method (Goulder, 2002).

3 Model Framework

The model is based on a simple comparative static model, "STAGE„ (McDonald, 2007). The STAGE model is a member of a family of computable-general equilibrium (CGE) models, which is based on the 1-2-3 model developed by de Melo and Robinson (1989) and Devarajan et al. (1990). The model is a Social Accounting Matrix (SAM) based single-country CGE model, which is implemented in General Algebraic Modeling System (GAMS) software. For this analysis, we modify the standard STAGE model by:

1. Incorporating factor-fuel[1] as well as inter-fuel[2] substitutions for non-energy producing sectors;

2. Incorporating a nested linear expenditure system for households, which distinguishes between energy and non-energy composites;

3. Disaggregating the electricity sector into four technologies: coal-fired, gas-fired, nuclear, and hydro, using a technology bundle approach.

The formal description of the model is introduced in Annex 1. The equation block for nesting structures is built using the dual approach, which implies a determination of unit cost functions (or price indices) and demand functions which are derived by applying Shephard's lemma. Moreover, the equation block for the production system as well as household demand is modelled using macro functions in GAMS, whose use is quite convenient for changing functional forms (e.g. standard CES, Cobb-Douglas, Leontief). All macro functions are located in the right hand side in equations, noted in small cases. The macro functions are listed in Annex A1.6.

4 Database

This analysis is based on Version 7 of the Global Trade Analysis Project (GTAP) database, which represents the global economy in 2004. The GTAP database describes bilateral trade, production, and consumption of 57 commodities and 113 regions (GTAP, 2007). The GTAP database does not, however, include any enterprise accounts, and one private household only is represented in the database. For our analysis we extract a Social Accounting Matrix (SAM) for Russia using the GAMS version of the SAM extraction program developed by McDonald and Thierfelder (2004). For this analysis, we aggregate 57 activities into 25 activities, where the SAM for Russia represents single product activities.

Another important issue is CO2 coefficients, which differ among energy commodities due to differences in emission contents. The CO2 coefficients are calculated based on the Energy Information Administration (EIA) database (2011), by dividing the total CO2 emission of a certain energy product (measured in million metric tons) by the total amount of energy used

[1] A factor-fuel substitution is a substitution between energy inputs and primary factor (Burniaux and Truong, 2002)

[2] An inter-fuel substitution is a substitution among energy inputs (Burniaux and Truong, 2002)

(measured in quadrillion Btu). Coal and petroleum products contain the largest emission contents. For example, the CO2 coefficient for coal is 92.81 million metric tons per quadrillion Btu, for petroleum products and crude oil (66.63), for natural gas, and gas manufacture (53.82). Moreover, following the GTAP emission database (Lee, 2008), CO2 coefficients of coal, crude oil, and petroleum products used by the petroleum sector equal zero since they are not flared, but instead are refined. The same assumption is made for natural gas used by gas manufacturing.

According to the GTAP initial database, there is a uniform tax on primary factors which amounts to 2.6%. This means that all industries pay a tax of 2.6% on the use of labour, capital, land, and natural resources. Taxes on labour use represent social security contributions; however, according to the Russian Tax Code, tax rates of social security contributions are larger, 26% in 2009 (and 34% in 2011) (Federal Law from 24. Jul.2009 No. 213-FZ). Therefore, we modify the database to accommodate these higher tax rates on skilled and unskilled labour, using a program coded in GAMS which is similar with ALTERTAX (Malcolm, 1998).

5 Experiments and Model Closures

Experiments

In this analysis we simulate an introduction of carbon taxes on energy commodities such as coal, natural gas, petroleum products, and gas manufacture used by households and industries. Carbon taxation is not applicable for crude oil since crude oil is consumed mainly by the petroleum sector. For instance, the share of crude oil consumption by the petroleum sector is 98% of domestic consumption (GTAP, 2007).

The magnitude of carbon taxation aims at a targeted reduction of carbon emissions by 10% through a proportional increase in tax rates on carbon emissions. This means that carbon taxes differ between energy commodities according to the CO2 coefficients, yet are the same among sectors and households. We consider two experiments:

1. An introduction of carbon taxes compensated by an increase in lump-sum subsidies to private households (CT_HS);
2. An introduction of carbon taxes compensated by a reduction of taxes on skilled and unskilled labour used by industries (CT_LT).

Furthermore, experiments are accompanied by a sensitivity analysis to verify the stability of the results and to recognize the important determinants:

- Different emission reduction targets;
- Capital immobility vs. capital mobility;
- Different labour supply elasticities;
- Different functional forms of the value-added aggregate;
- Different nesting structures of the energy aggregate;
- Different functional forms of the capital-energy aggregate.

Macroeconomic Closure and Market Clearing

In the model we assume the following closure rules:

- *Foreign Exchange Closure:* the external trade balance is fixed and the exchange rate is flexible so that changes in the exchange rate clear the foreign exchange market. This is because Russia has a flexible exchange rate regime;
- *Investment-Savings Closure:* volumes of investment are fixed and household savings rates are variable so that the capital accounts are cleared by changes in the household savings rate. The assumption of fixed investment is consistent with the long-run experiment;
- *Government Account Closure*: government savings rates and government consumptions are fixed so that the government account is cleared either by an increase in lump-sum subsidies or by a reduction of labour taxes;
- *Numeraire:* the consumer price index (CPI) is set as numeraire;
- *Factor Market Closure:* capital is assumed to be perfectly mobile among sectors; however, we assume immobility of natural resources. Land is used by the agricultural sector only, and hence it is a *de facto* immobile resource. Furthermore, we assume a perfectly elastic supply of land. This is because Russia has a large potential for land resources – a lot of useful land remains fallow. Therefore, it is expected that the supply of land should be quite elastic. The supply of skilled and unskilled labour is assumed to be inelastic. Therefore, we incorporate a supply function for skilled and unskilled labour:

$$FS_f = shfs_f * (WF_f * (1 - TYF_f))^{efs_f}$$

where FS_f is the supply of skilled and unskilled labour, $shfs_f$ is the shift parameter for the supply function, WF_f is the wage level, efs_f is the labour supply elasticity which is assumed to equal to 0.30, following Böhringer et al. (2001). Most studies find that labour supply is rather inelastic[3].

6 Carbon Taxation on Households and Industries

6.1 Macroeconomic and Aggregated Effects

Carbon Taxation Compensated by an Increase in Lump-Sum Subsidies

Table 6.1 shows macroeconomic and aggregated effects of carbon taxes imposed on energy commodities used by households and industries. An introduction of carbon taxes compensated by an increase in lump-sum subsidies (CT_HS) results in higher energy costs. This makes the overall economy less competitive compared to the world economy. Consequently, domestic production in most sectors decreases, resulting in a decline of the real GDP by 0.3%. Moreover, a CT_HS results in a loss of welfare, which is indicated by negative equivalent variation[4], 3072 millions USD.

Table 6.1 Macroeconomic and aggregated effects of carbon taxes (%)

	CT_HS	CT_LT
GDP	-0.31	0.52
Equivalent variation, millions USD	-3072	2575
Exchange rate	0.46	0.56
Value of total imports	-1.51	-0.75
Value of total exports	-1.02	-0.50
Household expenditure	-0.21	1.81
Saving rate	0.45	-0.98
Lump-sum subsidy	17.89	fixed
Labour taxes	fixed	-94.61
Household income	0.03	1.27
Factor income	-3.39	1.27
- Capital	-4.46	-3.77
- Natural resources	-3.81	-3.66
- Land	-0.77	1.15
- Skilled labour	-1.51	10.23
- Unskilled labour	-1.81	10.61
Factor prices		
- Capital	-4.46	-3.77
- Natural resources	-9.56	-6.85
- Land	fixed	fixed
- Skilled labour	-1.16	7.78
- Unskilled labour	-1.40	8.07

[3] According to various studies, the mean labour supply elasticity for men equals 0.07, whereas for women it is 0.43 (Evers et al. 2008).

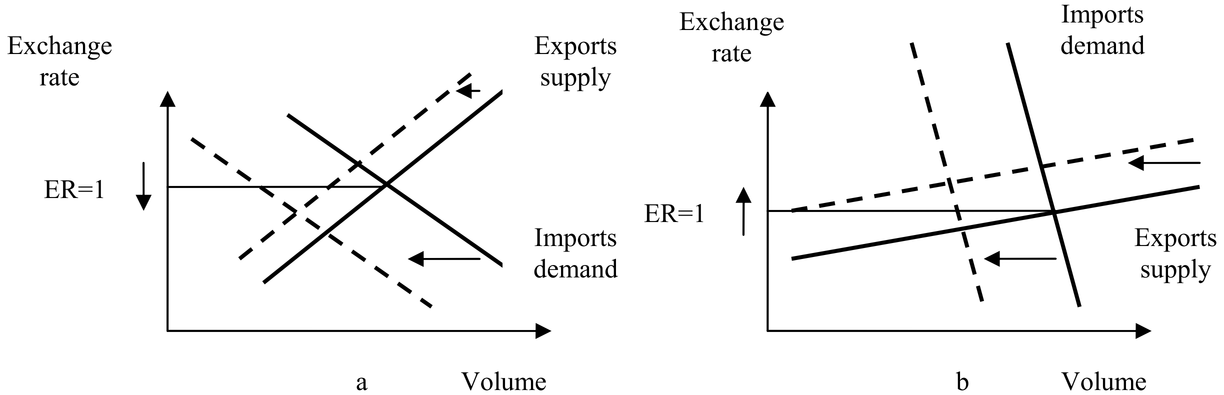
[4] Equivalent variation measures how much a consumer would pay before a price increase to avoid the price increase so that the income change is equivalent the price change regarding the utility change (Varian, 1999).

Factor supply		
- Land	-0.77	1.15
- Skilled labour	-0.35	2.27
- Unskilled labour	-0.42	2.35
Government income	-0.90	-2.14
Tax revenues		
- Import tariffs	-0.46	0.56
- Export tariffs	3.83	4.05
- Sale taxes	-4.20	-3.25
- Factor use taxes	-2.32	-72.06
- Factor income taxes	-2.37	6.92
- Carbon taxes, million USD	14768	15936
Subsidy expenditures		
- Production subsidy	-0.88	0.66
- Lump-sum subsidy	13.89	1.27

Source: model simulation results

A CT_HS leads to a reduction in total exports and imports of commodities due to a lower consumption and production level. This is shown in the decrease in the value of total imports by 1.5%, whereas the value of total exports decreases by 1.02% (Table 6.1). A reduction in total imports and exports can lead to a depreciation as well as an appreciation of the currency. This depends on two factors: the change in total exports compared to the change in total imports, and the aggregated elasticity of export supply compared to the aggregated elasticity of import demand. For example, if the aggregated elasticity of imports demand and the aggregated elasticity of export supply are equal, then a CT_HL would lead to an appreciation of the currency (Fig.6.1a). This is because the value of total imports demand decreases stronger compared to the value of total exports demand, which implies a stronger shift of imports demand curve compared to the exports supply curve.

Fig. 6.1 Trade balance.



Source: own compilation

According to the results, a CT_HL leads to an increase of exchange rate by 0.4%, which implies a depreciation of the currency, even though the reduction in total demand for imports is stronger than the reduction in total exports supply. This is because the import demand curve is more elastic compared to the export supply curve (Fig. 6.1b). Therefore, the depreciation of the currency results from a reduction in total exports and an elastic export supply curve compared to the import demand curve. Moreover, the reduction in total exports is mainly driven by a strong decline in exports of metals and chemicals: their value share amounts to 25% in the value of total exports.

Household income, which consists of factor income and lump-sum subsidies, increases by 0.03% because of higher lump-sum subsidies, whereas the total factor income decreases by 3.3% (Table 6.1). For example, income from natural resources decreases by 3.8% and income from capital decreases by 4.4%. The strong decline in income from natural resources results from a decline in domestic production of coal, natural gas, minerals, and agriculture. Moreover, the supply of land and labour decreases. Lump-sum subsidies increase by 17.8%, where the increase in revenues from carbon taxes is by 20% more than the increase in expenditures for lump-sum subsidies in value terms. Despite the increase in household income, household expenditure decreases by 0.2% because of a higher savings rate. According to the model closures, government savings, government consumption, and the volume of investment is fixed, which implies an investment driven closure. The value of investment, however, decreases because of decreasing prices of investment commodities such as construction. A decline in capital income and a depreciation of the currency leads to strong decline in the total savings[5]. As a result, the savings rate by households increases by 0.4% to clear the saving investment account. Alternatively, a saving driven closure (fixed savings rate) would result in an increase in household expenditure; however, this would significantly reduce investments.

As a result of lower production and consumption levels, revenues from almost all taxes decrease. For example, carbon taxation results in a strong reduction in revenues from sale taxes, by 4.2%. This is because revenues from sale taxes consist mainly of taxes on petroleum products and the domestic consumption of petroleum products decreases because of higher petroleum prices. On the other hand, revenues from export taxes and carbon taxes increase. Revenues from export taxes increase by 3.8% because export of crude oil and petroleum

[5] According to the model, total savings consist of fiscal depreciation, household savings, government savings, and foreign savings (borrowings) multiplies by the exchange rate. According to the database, Russia is a net borrowing of capital.

products increase and export taxes consists mainly of taxes on crude oil, metals, petroleum products, etc.

Carbon Taxation Compensated by a Reduction of Labour Taxes

Under a carbon taxation compensated by a reduction of labour taxes (CT_LT), the economy is less adversely affected by higher energy prices. As a result, the real GDP increases slightly by 0.5%, whereas under a CT_HS it decreases by 0.3%. Moreover, a CT_LT results in a welfare gain, which is indicated by positive equivalent variation, 2575 millions USD. The exchange rate increases by 0.5%, which implies a stronger depreciation of the currency compared to the depreciation of the currency under a CT_HS. This is because the reduction in total imports is less pronounced under CT_LT than under CT_HS. The reasons for the currency depreciation are explained above (Fig. 6.1b).

Household income increases proportionally to the increase in factor income, by 1.2%, whereas lump-sum subsidies are fixed. The increase in factor income results from higher income from land via an increase in agriculture production as well as from increased skilled and unskilled labour via lower labour taxes. In contrast, income from natural resources and capital decreases by 3.6% and 3.7%, respectively. The reduction in income from natural resources results from a decline in production of resource-based sectors such as coal, natural gas, and minerals. The reduction in capital income results from a decline in production of capital-intensive sectors such as the trade sector. Moreover, under a CT_LT the increase in household expenditures, by 1.8%, is stronger than the increase in household income because of a lower savings rate. This is demonstrated with the decrease in the savings rate by 0.9%. According to the model closures, government savings, government consumption, and the volume of investment is fixed, which implies an investment driven closure. The value of investment, however, decreases because of decreasing prices of investment commodities such as construction. As a consequence, the total savings decrease proportional to the decline in the value of investment. On one hand, a CT_LT leads to a decline in capital income and a depreciation of the currency, which results in a reduction of total savings. On the other hand, a higher household income provide more savings for the economy. Since the effect of a higher household income is stronger than the effect of currency depreciation and lower capital income, the savings rate decreases to match the decreasing demand for investment. Alternatively, if we fix the savings rate, investment in real terms would increase from higher household income; however, the increase in domestic demand would be less pronounced than it would be under investment driven closure.

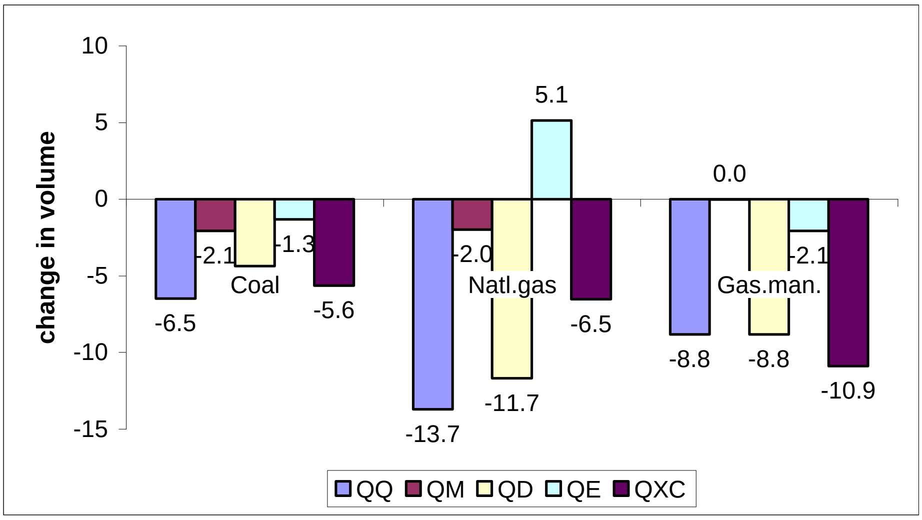
Furthermore, under a CT_LT most non-energy producing sectors face an increase in domestic production and consumption. Therefore, revenues from import tariffs, export tariffs, and factor income taxes increase. Revenues from taxes on factor income increase by 6.9%, and revenues from taxes on exports increase by 4.0%. In contrast, revenues from sale taxes and taxes on factor use decrease. The decline in revenues from sale taxes results from a reduction in domestic demand for petroleum products due to higher petroleum prices.

6.2 Energy Consumption and Energy Intensity

Energy Balance

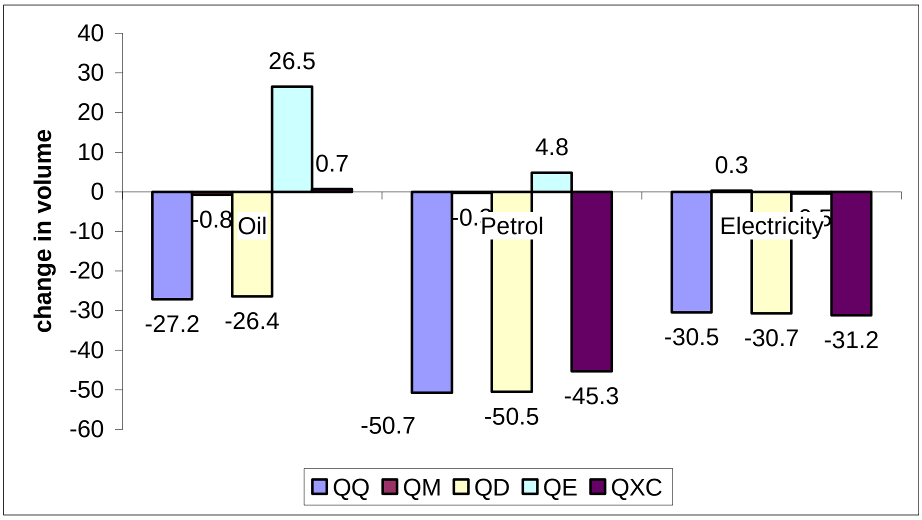
Fig. 6.2a and 6.2b illustrate absolute changes in the energy balance of Russia, which are measured in volume terms. For example, a CT_HS leads to a reduction in domestic consumption (QQ) of energy commodities, implying a decline in domestic demand for imported (QM) and domestically produced commodities (QD). The absolute reduction in demand for domestically produced energy commodities is stronger than the reduction in demand for imported commodities. This is because domestically produced energy commodities dominate in the domestic market: for example, electricity, crude oil, and gas manufacture markets are almost served by domestic producers. On the other hand, the relative reduction in demand for imports is stronger than the reduction in demand for domestically produced energy commodities because of depreciation of the currency.

Fig. 6.2a Change in energy balance under CT_HS (absolute change in volume).



Source: model simulation results

Fig. 6.2b Change in energy balance under CT_HS (absolute change in volume).



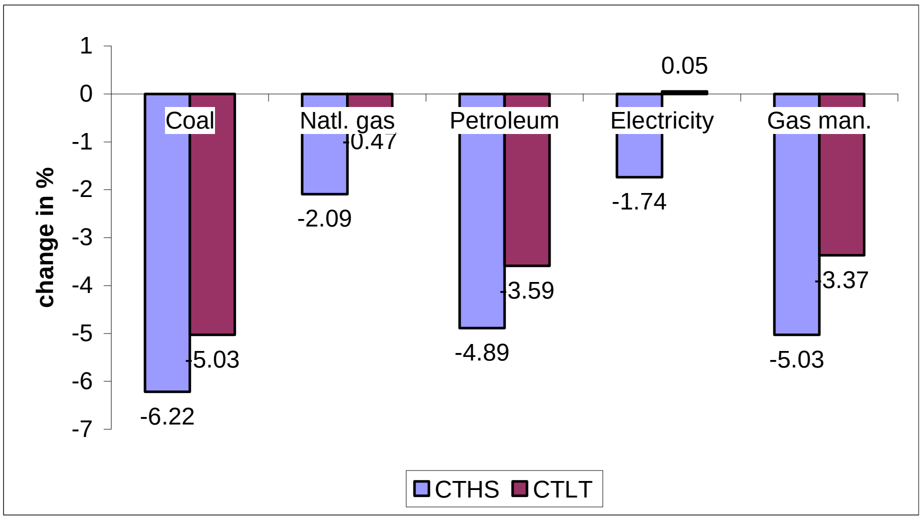
QQ is the domestic demand for the composite of imported and domestically produced commodities: QQ=QM+QD;
QM is the import;
QD is the domestic supply of energy commodities for domestic markets;
QE is the export; and,
QXC is total domestic production for domestic and export markets: QXC=QD+QE.
Source: model simulation results

A lower domestic demand results in a reduction in domestic production of all energy commodities, excluding crude oil. Moreover, a lower profitability in production of coal, gas manufacture, and electricity leads to an outflow of resources (capital, labour) from these sectors, resulting in decline in exports. In contrast, a depreciation of the currency induces a shift in production of crude oil, natural gas, and petroleum products towards export markets (Fig. 6.2a and 6.2b). The change in the energy balance under a CT_LT is quite similar.

Consumption of Energy Commodities by Households

As a result of higher energy prices, household consumption of energy commodities decreases. Fig. 6.3 illustrates the change in consumption of energy commodities used by households. As a result of a CT_HS, household consumption decreases by the following amounts: 6.2% for coal, 5.0% for gas manufacture, 2.0% for natural gas, and 4.8% for petroleum products. There are no carbon taxes on electricity; however, households demand for electricity decreases by 1.7% because of higher electricity prices.

Fig. 6.3 Change in household consumption of energy commodities (%).

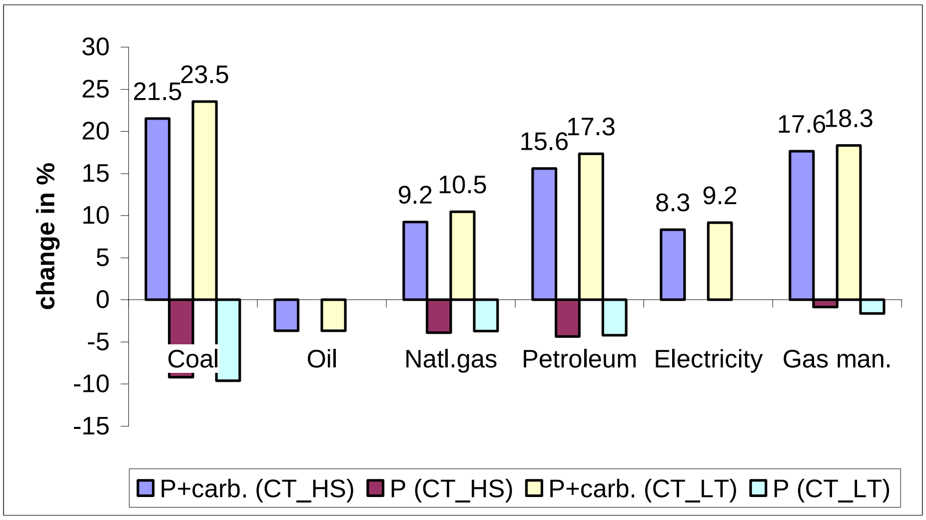


Source: model simulation results

Under a CT_LT, the reduction in household demand for energy commodities is less pronounced. This is because households face an increase in total factor income due to higher income from land and labour. Therefore, the decline in demand for energy commodities used by households is diminished by higher household expenditures.

Furthermore, a CT_LT leads to a higher increase in carbon taxes compared to a CT_HS. As a result, domestic prices of energy commodities including carbon taxes increase stronger under a CT_LT. Fig. 6.4 illustrates the change in consumer prices of energy commodities including and excluding carbon taxes under different revenue recycling strategies.

Fig. 6.4 Change in consumer prices of energy commodities including and excluding carbon taxes under different revenue recycling strategies (%).

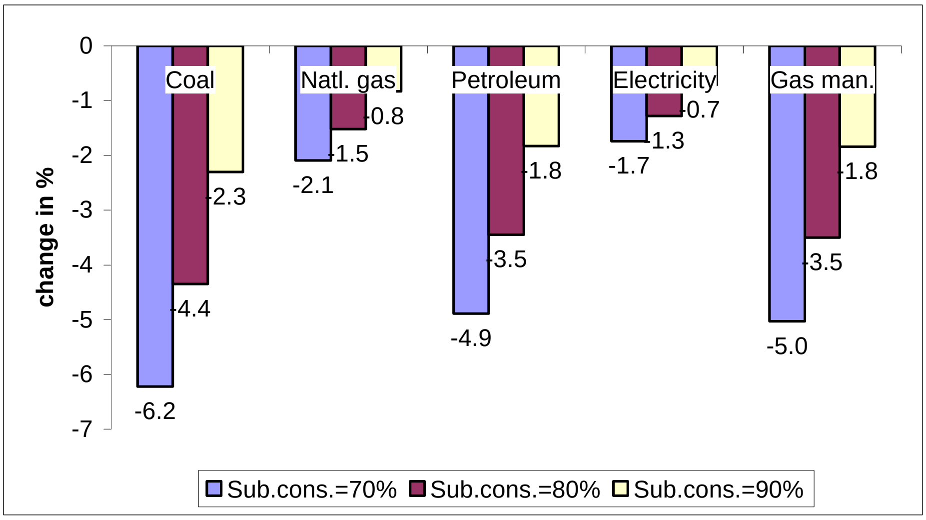


P+carb. (CT_HS) is the consumer price, including the carbon tax, under a CT_HS;
P (CT_HS) is the consumer price, excluding the carbon tax, under a CT_HS;
P+carb. (CT_LT) is the consumer price, including the carbon tax, under a CT_LT; and,
P (CT_LT) is the consumer price, excluding the carbon tax, under a CT_LT.
Source: model simulation results

An introduction of a CT_HS leads to an increase by 21.5% in the consumer price of coal, 9.2% for natural gas, 15.6% for petroleum products, 17.6% for gas manufacture. The consumer price of electricity increases by 8.3% because of higher production costs. In contrast, the consumer price of crude oil decreases slightly due to lower production costs. As mentioned above, crude oil is not a subject for carbon taxation.

In the base simulation, the level of subsistence consumption is assumed to equal 70%. At the same time, household demand for energy commodities significantly depends on the level of subsistence consumption (Fig. 6.5). Under a higher level of subsistence consumption, the reduction in consumption of the energy composite is less pronounced. For example, when the level of subsistence consumption equals 90%, household consumption of coal decreases by 2.3%, for gas manufacture it decreases by 1.8%, for electricity it decreases by 0.7%, and for petroleum products it decreases by 1.8%.

Fig. 6.5 Change in consumption of energy commodities by households under different levels of subsistence consumption (%).



Source: model simulation results

Moreover, the rates of carbon taxes are higher under a lower level of subsistence consumption. This results in higher energy costs for industries. As a result, the economy is more adversely affected by higher carbon taxes. The difference between the total consumption level and the level of subsistence consumption may partially be considerated as a proxy for the potential energy efficiency potential of households that could be realized through higher energy prices. The level of subsistence consumption in relation to current consumption is expected to be relative high in Russia because of low household income.

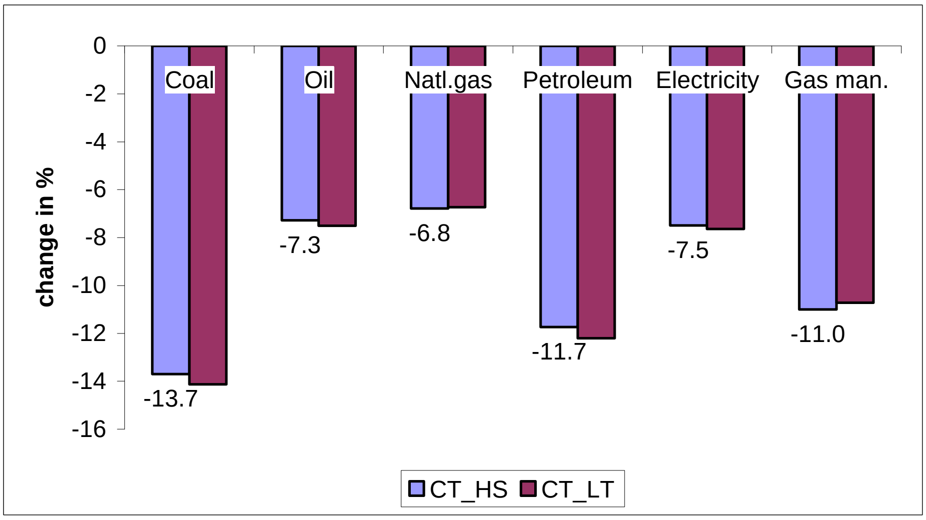
Consumption of Energy Commodities by Industries

As a result of carbon taxes, demand for energy commodities such as coal, natural gas, petroleum products, and gas manufacture decreases for all industries. Fig. 6.6 reveals the change in the overall demand for energy inputs used by industries. The most adversely affected energy sectors are coal, petroleum products, and gas manufacture because of their high CO2 emissions.

Most sectors, however, face an increase in demand for crude oil through inter-fuel substitutions since crude oil is not taxed by carbon taxes. Moreover, carbon taxation leads to an increase in demand for coal by sectors such as paper products, transport equipment, and minerals because of increasing production. This implies an increase in carbon emissions produced by these sectors.

Under a CT_HS, the total demand for crude oil by all sectors decreases by 7.3% because of a decline in domestic production of petroleum products: the petroleum sector is the largest domestic consumer of crude oil with a share of 98% in the total domestic consumption of crude oil (GTAP, 2007). Moreover, the total demand for electricity used by sectors decreases by 7.5% because of higher electricity prices. The reduction in domestic demand for energy commodities under a CT_LT is quite similar with those under a CT_HS (Fig. 6.6).

Fig. 6.6 Change in consumption of energy commodities used by industries (%).



Source: model simulation results

Carbon taxation on households and industries allows an avoidance of sectoral carbon leakages. For example, under carbon taxation on industries only, the domestic price level for energy commodities used by households would decrease. This would imply an increase in the final demand for energy commodities used by households. A similar effect occurs under carbon taxation on households only. Under carbon taxation on households and industries, the decline in domestic production would be less pronounced since households and industries take the burden of carbon taxation; however, the extent of this decline significantly depends on the level of subsistence consumption.

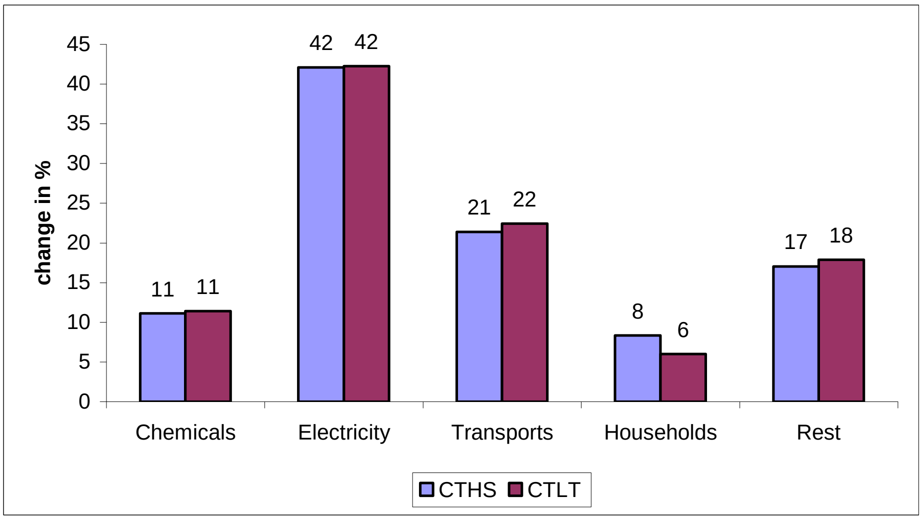
Energy Intensities

The main channel of a reduction in energy intensities of the whole economy is through a decline in domestic production which results from structural change towards less energy-intensive sectors, implying a decline in demand for energy resources. Moreover, energy intensities can also decrease through technological progress and substitution possibilities among primary factors and energy inputs. In this analysis, we consider substitution possibilities among primary factors and energy inputs only. A technological progress is not considered in this study. The change in energy intensities differ from sector to sector depending on the initial energy and factor intensities of the sector. The energy intensity is calculated by dividing the amount of total energy consumed by output. Under a Leontief nesting structure, the energy intensity would be constant. For example, the energy intensity of the transport sector decreases by 7.2%, which means that the transport sector requires 7.2% less energy resources for producing a unit of output. The maximum reduction of energy intensity through substitution in production does not exceed 9% (Annex Table A3).

Carbon Emissions

The magnitude of carbon taxation aims at a targeted reduction of overall carbon emissions by 10%. This reduction of carbon emissions is mainly achieved through a decline in domestic demand for energy commodities by sectors such as electricity, transports, and chemical products. Fig. 6.7 illustrates the shares of emission reductions by industries and households.

Fig. 6.7 Shares of CO2 emission reductions by sources (%).



Source: model simulation results

For example, a reduction of energy use by the electricity sector accounts for 42% of the overall reduction of carbon emissions, for the chemicals sector it is 11%, for transports it is between 21 and 22%, and for all other sectors it is between 17 and 18%. In addition, a reduction of energy consumption by households contributes between 17 and 18% to the overall reduction of carbon emissions.

The electricity sector is the largest domestic contributor of emissions. According to the Fifth National Report of Russian Federation (UNFCCC, 2010) the power generation sector produces about 81% of total GHG emissions in Russia. Moreover, about 41% of the total technical energy saving potential is concentrated in the Russian power generation sector (electricity and heat) since the power generation sector is the largest domestic consumer of energy resources (Bashmakov, 2009). Therefore, the power generation sector is expected to play the crucial role in Russia's environmental policy.

6.3 Sectoral Effects

Carbon Taxation Compensated by an Increase in Lump-Sum Subsidies

Table 6.3 reveals sectoral effects of carbon taxes on households and industries. An introduction of a CT_HS leads to a reduction in domestic production in most sectors due to higher energy costs and lower domestic demand: domestic production of coal decreases by 8.3%, for natural gas it decreases by 2.8%, for petroleum products it decreases by 7.4%, and for gas manufacture it decreases by 8.7%.

Table 6.3 Change in average costs and domestic production (%)

Industries	CT_HS		CT_LT	
	Average costs	Domestic	Average costs	Domestic

		production		production
Agriculture	-0.21	-0.72	-0.65	1.27
Coal	-6.41	-8.35	-6.68	-8.39
Crude oil	-1.29	0.08	-1.23	0.04
Natural gas	-4.01	-2.80	-3.82	-2.80
Minerals	-2.54	-1.94	-2.51	-1.36
Food products	-0.62	-0.40	-0.79	1.59
Textiles	-0.12	-0.13	-0.44	2.55
Wood products	3.94	-11.34	4.08	-10.32
Paper products	-1.20	0.94	-1.32	2.66
Petroleum products	-3.31	-7.47	-3.17	-7.66
Chemical products	4.16	-11.72	4.47	-11.21
Mineral products	1.36	-1.72	1.24	-1.20
Metals	1.33	-6.19	1.53	-5.86
Metal products	0.90	-2.54	0.63	-1.07
Transport equipment	-0.18	0.72	-0.38	2.68
Electronic equipment	1.22	-2.36	1.18	-1.29
Machinery equipment	0.24	-0.79	-0.23	0.43
Electricity	8.35	-5.66	9.20	-5.16
Gas manufacture	-0.59	-8.76	-1.19	-7.91
Water	0.10	-1.04	-0.52	0.09
Construction	-1.11	-0.21	-1.33	-0.01
Trade	-2.61	-1.04	-2.34	0.23
Transports	1.95	-2.84	2.01	-1.72
Private services	-1.54	-0.84	-1.82	0.32
Government services	-0.82	-0.05	-1.97	0.26

Source: model simulation results

The electricity sector is the largest domestic consumer of coal, gas, and gas manufacture and is a large domestic consumer of petroleum products. Therefore, this sector, in particular, is strongly affected by higher energy prices. As a result of carbon taxes, average production costs of electricity generation increase by 8.3%. Consequently, all electricity-intensive sectors such as wood products, chemical products, metals, metal products, mineral products, and water, are adversely affected by higher electricity prices since electricity is a significant part of the total production costs for these sectors. For example, in the wood products sector the share of electricity costs of total production costs is 43.7%, for chemical products it is 18.7%, for metals it is 14.1%, and for water it is 13.8% (GTAP, 2007). As a result, higher energy costs lead to higher average production costs in these sectors, even though costs for primary factors decrease. Domestic production of wood products and chemical products is reduced by 11.3% and 11.7%, respectively. In contrast, average production costs decrease in sectors such as agriculture, minerals, construction, trade, and services. However, lower domestic demand leads to a decline in domestic production of these commodities.

Furthermore, a CT_HS leads to an increase in domestic production of crude oil, paper products, and transport equipment due to lower production costs. In other words, the effect of lower factor costs overweighs the effect of higher energy costs due to the lower energy intensity in these sectors compared to others. The change in average costs results from changes in structure in production costs, which is indicated by changes in activity prices (Annex Table A4). Introducing carbon taxes leads to a decline in costs for capital, where the activity price of the energy aggregate increases. The change in activity prices of capital-energy aggregates depends on the capital-energy intensity of sectors. Moreover, activity prices of the labour aggregates decrease under a CT_HS and CT_LT in all sectors. Therefore, the change in activity prices of value-added-energy aggregates mainly depends on labour intensity. The change in activity prices of intermediate aggregate is relative small and different from sector to sector. Therefore, labour intensive sectors have a decline in average production costs despite an increase in energy costs.

Carbon Taxation Compensated by a Reduction of Labour Taxes

Under a CT_LT, we observe a stronger increase in domestic production of commodities such as paper products and transport equipment because of higher domestic demand and lower production costs (Table 5.3). Moreover, a higher household income and lower labour costs result in an increase in domestic production of commodities such as agriculture, food products, textiles, machinery equipment, water, trade, and services. Therefore, under a CT_LT the structural change to non-energy producing sectors is more pronounced compared to under a CT_HS.

Imports and Exports

A CT_HS leads to lower household expenditures. As a result, imports of almost all commodities decrease (Table 6.4[6]). Furthermore, the reduction in imports of energy commodities is stronger compared to non-energy commodities because carbon taxes are imposed on domestic as well as imported energy commodities. However, Russia is a large energy producer and exporter, the amount of imported energy commodities is rather negligible.

Table 6.4 Change in exports and imports (%)

Industries	CT_HS		CT_LT	
	Exports	Imports	Exports	Imports
Coal	-5.04	-25.53	-4.90	-26.45

[6] For changes of exports and imports in other sectors see Annex Table A3.

Crude oil	5.52	-16.90	5.61	-17.33
Natural gas	14.63	-36.37	14.32	-35.84
Wood products	-19.95	3.57	-19.11	4.92
Petroleum products	3.80	-15.03	3.46	-15.13
Chemical products	-16.38	2.05	-16.14	3.40
Metals	-8.57	-0.66	-8.52	0.30
Electronic equipment	-2.73	-0.29	-1.60	0.41
Electricity	-9.16	5.00	-8.99	6.58
Gas manufacture	-8.28	-10.55	-7.09	-10.91
Transports	-7.03	-0.43	-5.84	0.64

Source: model simulation results

In contrast, imports of wood products, chemical products, and electricity increase as a result of both revenue recycling strategies. As a result of higher production costs, domestically produced wood products, chemical products, and electricity become less competitive compared to imported commodities. Therefore, the substitution effect dominates the negative output effect. Nevertheless, total domestic consumption of wood products, chemical products and electricity decreases because of a strong increase in domestic prices.

In comparison, under a CT_LT we also observe more of an increase in imports of metals, electronic equipment, and transports. This is because of higher household income which drives domestic demand for non-energy commodities.

Furthermore, carbon taxation under the both revenue recycling strategies results in a strong increase in the export supply of natural gas. Exports of natural gas increase by 14.3%, which may imply strong leakage effects in countries that import Russian natural gas. In contrast, the export supply of wood products and chemical products decreases strongly. Under a CT_HS, the export supply of wood and chemical production is reduced by 19.9% and 16.3%, respectively. In addition, under a CT_LT the increase in the export supply of some sectors is more pronounced than under a CT_HS because of a lower increase in production costs and a stronger depreciation of the currency.

6.4 Technological Change in the Electricity Sector

As mentioned above, the electricity sector is one of the most adversely affected sectors by the introduction of carbon taxation. This is because the electricity sector is the largest domestic consumer of natural gas, coal, and gas manufacture and also a large domestic consumer of petroleum products. A CT_HS results in a decline in domestic production of electricity by 5.6% (Table 6.5). Moreover, technologies such as nuclear and hydro become more profitable compared to thermal technologies. For example, output from nuclear and hydro technologies increases by 13.8% each while output from coal-fired technologies decreases by 12.06% and output from gas-fired technologies decreases by 5.4%.

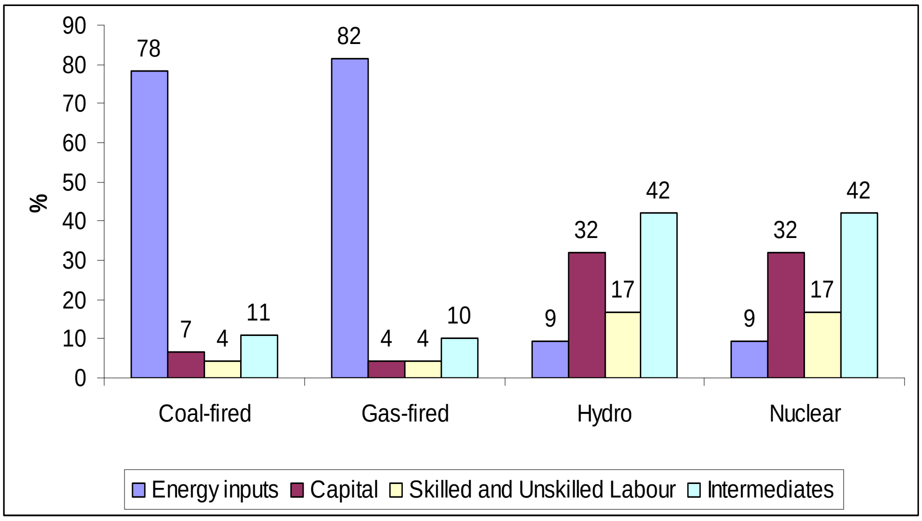
Table 6.5 Change in output of electricity from different electricity generation technologies (%)

	Output (elast.=2.00)		Output (elast.=1.50)		Output (elast.=0.50)	
	CT_HS	CT_LT	CT_HS	CT_LT	CT_HS	CT_LT
Coal-fired	-12.06	-12.19	-10.90	-10.92	-8.15	-7.87
Gas-fired	-5.47	-4.95	-5.59	-5.06	-6.08	-5.58
Hydro	13.83	16.32	8.98	11.01	-1.19	-0.18
Nuclear	13.83	16.32	8.98	11.01	-1.19	-0.18
Total	**-5.65**	**-5.16**	**-5.85**	**-5.36**	**-6.27**	**-5.79**

Source: model simulation results

Output from coal-fired technologies decreases stronger compared to gas-fired technologies. This is because carbon taxes on coal are higher than carbon taxes on gas because of higher CO2 coefficients. Coal-fired technologies, however, are assumed to be more capital-intensive compared to gas-fired technologies (Fig. 6.8).

Fig. 6.8 Cost structure by electricity technologies (% of total costs)



Source: own calculation based on the version 7 of the GTAP database; EIA (2011); APEC (2006); Veselov et al. (2010)

At the same time, carbon taxation leads to a reduction in capital costs, yet the effect of higher energy costs overweighs that of lower capital costs. Therefore, average production costs for coal-fired technologies increase more compared to that of gas-fired technologies (Table 6.5).

Furthermore, lower elasticities of substitution among technologies diminishes the extension of nuclear and hydro technologies in favour of thermal technologies such as coal- and gas-fired technologies. Under an elasticity of substitution equals to 1.5, the decrease in output from coal- and gas-fired technologies is less pronounced, while the increase of hydro and nuclear technologies is also lower. Under an elasticity of substitution equals to 0.5, all technologies operate like complements: an introduction of carbon taxes results in a decline in output for all technologies with the decrease from coal-and gas-fired technologies being more pronounced because of higher energy costs (Table 5.5).

7 Sensitivity Analysis

7.1 Carbon Taxation under Different Emission Reduction Targets

A CT_HS under higher targets of emission reductions results in a stronger decline in domestic production in most sectors. This is because higher carbon taxes imply higher energy costs. Therefore, the economy is more adversely affected by higher energy prices. In contrast, under higher targets of emission reductions we observe a larger increase in domestic production of crude oil, paper products, and transport equipment because of lower costs for primary factors. Generally, under higher targets of emission reductions, the macroeconomic and sectoral effects of carbon taxes are more pronounced.

Furthermore, under higher targets of emission reductions, a CT_LT results in a larger decline in domestic production of most energy-intensive sectors. However, we also observe a stronger increase in domestic production of commodities such as agriculture, crude oil, food, textiles, crude oil, paper products, and transport equipment. Moreover, under a reduction of carbon emissions by 20%, we observe a decline in domestic production of sectors such as water and trade due to a lower level of overall production and consumption. A reduction of carbon emission by 30% would result in decline of the real GDP by 0.07%, thereby implying a decline in domestic production of most sectors.

7.2 Carbon Taxation under the Assumption of Capital Immobility

Under the assumption of capital mobility, a CT_HS results in an increase in domestic production of crude oil, paper products, and transport equipment due to lower production costs. Capital mobility is consistent with the assumption of long-run experiments. However, under the assumption of sectoral immobility of capital, domestic production of paper products and transport equipment decreases due to lower domestic demand. Therefore, there is only an increase in domestic production of crude oil, whereas the domestic production of all other commodities decreases. Generally, under capital immobility the economy is more adversely affected by carbon taxes due to a smaller adjustability in production. Therefore, declines in domestic production of most sectors become more pronounced.

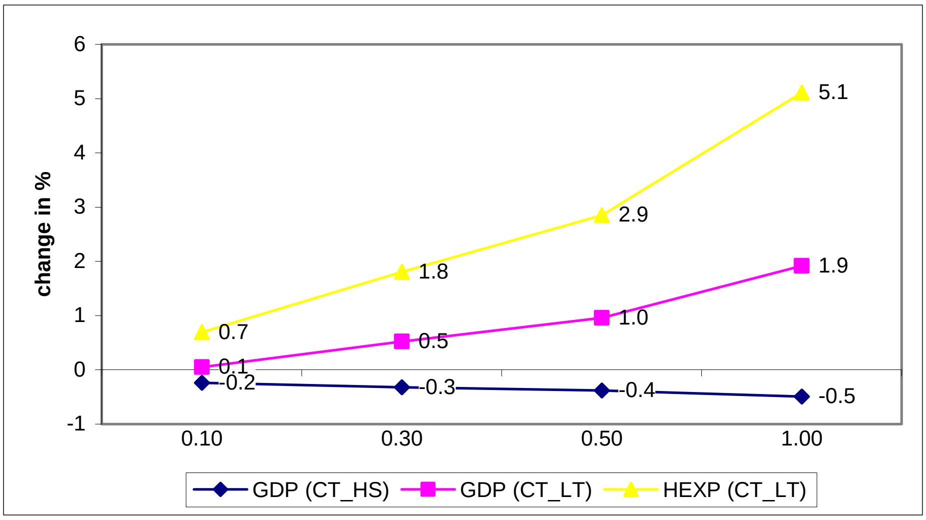
Under the assumption of capital immobility, a CT_LT has similar impacts as under the assumption of capital mobility. However, the increase in domestic production of sectors such as agriculture, food products, textiles, paper products, machinery equipment, water, and trade is less pronounced due to rigidity in the capital market. In addition, under capital immobility, carbon taxes lead to an increase in the export supply of petroleum products by approximately 30% under both revenue recycling strategies, whereas under capital mobility it increases between 3.4 and 3.8%, respectively.

Moreover, capital immobility implies a less elastic demand for energy inputs used by industries. As a result, the increase in carbon tax rates is more pronounced, implying more revenues from carbon taxes. Finally, carbon taxation under capital immobility leads to an appreciation of the currency, whereas under capital mobility the currency depreciates. Currency appreciation is mainly the result of a relatively strong increase in the export supply of petroleum products and natural gas, where the total export curve becomes less elastic because of rigidity in the capital market (Fig. 5.1a).

7.3 Carbon Taxation under Different Labour Supply Elasticities

The labour supply elasticity has a significant impact on the effects of carbon taxation. A higher labour supply elasticity results in less of an increase in net wages. As a result, the decline in labour costs is more pronounced compared to when a lower labour supply elasticity is assumed. As shown in Fig. 7.1, under a labour supply elasticity equals to 0.1, a CT_LT leads to an increase in the real GDP by 0.05% and household expenditures increase by 0.6%. Equivalent variation amounts to (-568) millions USD, implying a welfare loss. On the other hand, under a labour supply elasticity equals to 1.00, the real GDP increases by 1.9% and household expenditures by 5.1%. Equivalent variation amounts 11760 million USD, which indicates a welfare gain. As a result of higher household income and lower labour costs, the increase in domestic production of most non-energy producing commodities is larger under a higher labour supply elasticity compared to under a lower labour supply elasticity.

Fig. 7.1 Change of the real GDP and household expenditures under different labour supply elasticities (%).



GDP (CT_HS) is a change of the real GDP under a CT_HS;
GDP (CT_LT) is a change of the real GDP under a CT_LT; and,
HEXP (CT_LT) is a change of the real household expenditure under a CT_LT.
Source: model simulation results

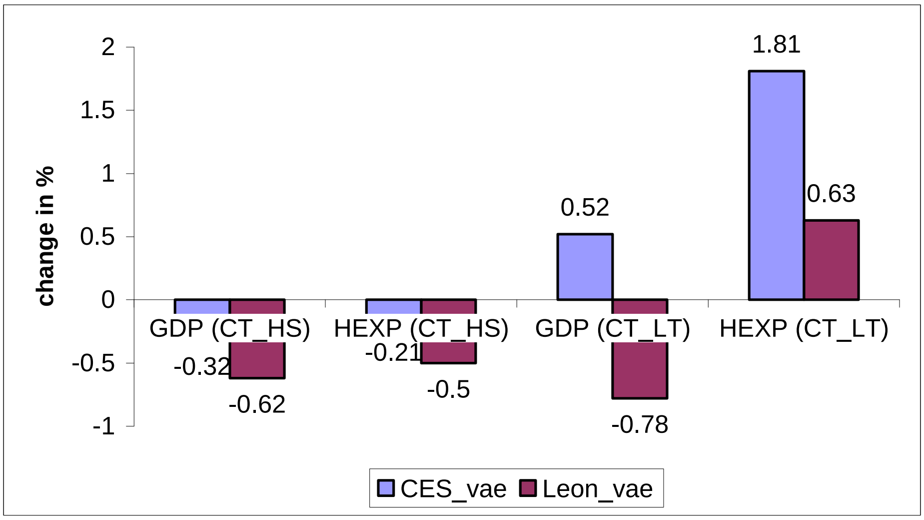
Furthermore, under a perfectly inelastic supply of labour as well as under an assumption of uniform taxes on labour, a CT_LT would induce the same macroeconomic and sectoral effects as a CT_HS. This is because a proportional reduction of uniform labour taxes is fully absorbed by a proportional increase in wages due to increased demand for labour. In other words, the increase in wages compensates for the decline in labour taxes.

On the other hand, under a CT_HS, a higher labour supply elasticity has an adverse affect on the economy because they imply a lower decline in wages compared to that under a CT_HS. At the same time, lower labour costs alleviate the negative effect of higher energy costs. A higher labour supply elasticity results in a stronger decline in domestic production of most sectors. As a result, real GDP as well as household expenditures decrease stronger under a higher labour supply elasticity. For example, under a labour supply elasticity equals to 0.1, a CT_HS leads to a decline in the real GDP by 0.2%, whereas under a labour supply elasticity equals to 1.0 the real GDP decreases by 0.5%. In addition, under a labour supply elasticity equals to 1.0, a CT_HS results in a larger welfare losses, which are indicated by equivalent variation equals (-4612 million USD), whereas under a labour supply elasticity equals 0.1 it is (-2556) million USD.

7.4 Carbon Taxation under Different Functional Forms of the Value-Added Aggregate

Generally, the results can be quite sensitive to model specifications and parameterisations such as Armington elasticities, elasticities of transformation, nesting structures, elasticities of substitution among primary factors, etc. However, the design of the model is important, especially at the stage in which the shock occurs. For example, under a CT_LT the elasticities of substitution between labour and the capital-energy aggregate have a significant impact on the results. Without any possibility of substitution between labour and the capital-energy aggregate, the economy is affected more adversely by higher energy costs since industries are less able to adjust to higher energy prices. Under the Leontief function between labour and the capital-energy aggregate, a CT_LT results in welfare losses in the amount of (-1320) million USD with a reduction of the real GDP by 0.7%. In comparison, under the standard CES function, a CT_LT leads to welfare gains of 2574 million USD, where the real GDP increases by 0.5% and household expenditures increase by 1.8% (Fig. 7.2).

Fig. 7.2 Change of the real GDP and household expenditures under the CES and Leontief function for the energy-value added aggregate (%).



GDP (CT_HS) is a change of the real GDP under a CT_HS;
HEXP (CT_HS) is a change of the real household expenditures under a CT_HS;
GDP (CT_LT) is a change of the real GDP under a CT_LT; and,
HEXP (CT_LT) is a change of the real household expenditure under a CT_LT.
Source: model simulation results

Without substitution possibilities between labour and the capital-energy aggregate, a CT_HS leads to a decline in the real GDP by 0.6% and a decline in household expenditures by 0.5%, whereas with substitution possibilities the real GDP and household expenditures decrease by 0.3% and 0.2%, respectively. In addition, welfare losses are larger without substitution between labour and the capital-energy aggregate: for instance, equivalent variation amounts to (-4217) million USD.

7.5 Carbon Taxation under Different Functional Forms of the Capital-Energy Aggregate

In this section, we investigate the effects of carbon taxes under different functional forms of the capital-energy aggregate. Therefore, we consider two cases: a CES function and a

Leontief function of the capital-energy aggregate for the non-energy producing sectors. Under a CES function, capital and the energy aggregate are substitutes and depicted by a two-argument CES function with an elasticity of substitution equals 0.50. A Leontief function implies that capital and energy inputs are complements. Capital is internationally immobile for both cases.

Without any substitution possibilities between capital and the energy aggregate, the economy is affected less adversely by carbon taxes under both revenue recycling strategies. If capital and energy inputs are complements, the decline in demand for capital is more pronounced, which implies lower capital costs. For example, without any substitution possibility, a CT_HS leads to a welfare loss measured in EV of 2952 million USD, where the real GDP decreases by 0.2% and household expenditure increases by 0.1%. In comparison, with substitution possibilities a welfare loss measured in EV amounts to 3072 million USD, where the real GDP decreases by 0.3% and household expenditures decreases by 0.2%. In addition, without substitution possibilities a CT_LT leads to a welfare gain measured in EV of 5177 million USD, accompanied by an increase in the real GDP by 1.0% and an increase in household expenditures by 3.0%. In contrast, with substitutions between capital and the energy aggregate, a welfare gain amounts to 2574 million USD, where the real GDP increases by 0.5% and household expenditures increase by 1.8%.

7.6 Carbon Taxation under Different Nesting Structures of the Energy Aggregate

In this section, we investigate the effects of carbon taxation under different nesting structures of the energy aggregate. Therefore, we introduce a CT_HS by considering three nesting structures for non-energy producing sectors: a CES nesting structure, a Leontief nesting structure and a GTAP nesting structure. The GTAP nesting structure is the “standard” case, where the energy aggregate is built according to the GTAP nesting structure. Under the CES nesting structure, the energy aggregate is described by a CES function over energy inputs such as coal, natural gas, gas manufacture, petroleum products, and crude oil, with an elasticity of substitution equals 0.5. Under the Leontief nesting structure, all energy inputs are complements and are depicted by a Leontief function.

Generally, with less substitution possibilities among energy inputs, the economy is affected more adversely by carbon taxes since industries become less adjustable for higher energy prices. As a result, under the Leontief nesting structure the decline in domestic production of most non-energy producing sectors is more pronounced than under the GTAP or CES nesting structures. In contrast, the increase in domestic production of crude oil, paper products and transport equipment is stronger under the Leontief nesting structure than under the GTAP and CES structures. However, these differences are rather negligible, in particular between the CES and GTAP nesting structures.

In addition, because of a lower production and consumption level under the Leontief nesting structure, revenues from almost all taxes decrease more compared to under the GTAP and CES nesting structures. In addition, exports of energy commodities such as crude oil, natural gas, and petroleum products increase stronger under the Leontief nesting structure than under the GTAP and CES structures. Moreover, under the Leontief nesting structure, the domestic demand for energy inputs becomes less elastic, resulting in higher carbon taxes and thus higher revenues from carbon taxes.

8 Summary of Results

Carbon Taxation Compensated by an Increase in Lump-Sum Subsidies

An introduction of a CT_HS results in a reduction in domestic production of most sectors due to higher energy costs and lower domestic demand, which implies a decline in both the real GDP and in household expenditures. Higher energy prices make the economy less competitive compared to the world economy. Therefore, the negative effect of higher energy costs overweighs the positive effect of higher lump-sum subsidies.

The electricity sector is the most adversely affected sector because of higher prices of energy inputs since this sector is the largest domestic consumer of coal, natural gas, and gas manufacture and is also a large consumer of petroleum products. At the same time, most other sectors are strongly affected because of higher electricity prices. In particular, electricity-intensive sectors such as wood products, chemical products, metals, minerals, and mineral products are greatly impacted from higher electricity prices. In contrast, domestic production increases for sectors such as crude oil, paper products, and transport equipment because of lower factor costs.

In addition, higher energy prices result in less carbon-intensive electricity technologies such as nuclear and hydro to become more profitable. Therefore, output of electricity produced using hydro and nuclear technologies increases, whereas output from coal- and gas-fired technologies decreases. Moreover, the decline in output from coal-fired technologies is more pronounced since carbon taxes on coal are higher than carbon taxes on gas. Therefore, average costs of coal-fired technologies increase more than average costs of gas-fired technologies. In addition, technological change in the electricity sector strongly depends on the elasticity of substitution among technologies. For example, under lower elasticities we observe a decline in output from all technologies since these technologies operate as complements.

Furthermore, we observe a decline in revenues from almost all taxes, except for revenues from export taxes and carbon taxes. Revenues from export taxes increase because they consist mainly of export taxes on crude oil, petroleum products, minerals, metals, etc., and the export supply of crude oil, petroleum products, and natural gas increases. We also find that under capital immobility, which is consistent with a short-run simulation, there is an appreciation of the currency. Therefore, an introduction of a CT_HS may lead to a Dutch disease problem in Russia.

Carbon Taxation Compensated by a Reduction in Labour Taxes

An introduction of a CT_LT results in an increase in domestic production of most non-energy producing sectors, which results in a small increase in the real GDP and household expenditures. The increase in domestic production is especially pronounced for the sectors of food, textiles, agriculture, and transport equipment. As a result of lower labour taxes, the economy is affected less adversely by carbon taxes compared to under a CT_HS. In contrast, domestic production in all energy sectors (excepting for crude oil) as well as electricity-intensive sectors decreases because of lower domestic demand and/or higher energy costs. The change in the economic structure in favour of non-energy producing sectors is more pronounced under a CT_HS compared to a CT_LT.

In addition, carbon taxation under both revenue recycling strategies may lead to strong carbon leakage in countries that import Russian natural gas. This is because the export supply of natural gas increases by 14 to 15%. Moreover, under capital immobility, carbon taxation results in a strong (30%) increase in the export supply of petroleum products.

Sensitivity Analysis

Higher targets of carbon emissions reduction have a more pronounced effect on the economy compared to lower targets, yet the direction of changes remains the same. For example, under higher targets of carbon emissions reduction, a CT_HS results in a stronger decline in domestic production for almost all sectors. In contrast, the increase in domestic production of crude oil, transport equipment, and paper products is more pronounced.

Under capital immobility, the economy is affected more adversely by carbon taxes due to a smaller adjustability in production. Therefore, the decline in domestic production of most sectors becomes more pronounced. For example, under capital immobility a CT_HS results in an increase in domestic production of crude oil, whereas domestic production in all other sectors decreases. Capital immobility is consistent with the assumption of short-run simulations.

Furthermore, a CT_LT may induce a double dividend in Russia, but it significantly depends on the labour supply elasticity as well as elasticities of substitution between labour and the capital-energy aggregate. A higher labour supply elasticity results in a lower increase in net wages. Therefore, the decline in labour costs is more pronounced under a higher labour supply elasticity. Moreover, higher elasticities of substitution between labour and the capital-energy aggregates encourage the shift of the tax burden from labour to capital. This makes the tax system more efficient. As a result, a CT_LT may lead to a stronger increase in the domestic production of most non-energy producing sectors under a higher labour supply elasticity and higher elasticities between labour and the capital-energy aggregate. This results in a stronger increase in both the real GDP and household expenditures.

Without any substitution possibilities among capital and energy commodities, the economy is less adversely affected by carbon taxes under both revenue recycling strategies. The main reason for this is that without substitution possibilities among capital and energy commodities, the shift of the tax burden to capital is more pronounced, which results in a stronger reduction of capital costs. In contrast, without any inter-fuel substitution possibilities, industries are more adversely affected by carbon taxes due to higher energy costs. Higher energy costs result in a stronger decline in the domestic production of most sectors because of less adjustability in production regarding the energy mix. Differences in the results under the GTAP, CES, and Leontief nesting structure are rather negligible.

In addition, lower substitution possibilities in production among primary factors as well as energy inputs result in lower elasticities of demand for energy commodities used by industries. Therefore, the increase of carbon taxes is more pronounced under less flexible production structures, which implies a stronger increase in revenues from carbon taxes.

9 Conclusions

Introducing carbon taxes in Russia can provide large economic and environmental benefits. For example, in the short to medium terms they would, *inter alia*, (1) reduce the emission of

CO_2 and other emissions such as CH_4, N_2O, and SF_6, which are stemming from the use of energy commodities, induce energy users to (2) optimize the use of existing plant, (3) substitute lower emission energy source for higher emission sources and (4) adopt passive energy saving technologies, e.g., improved insulation. In the longer term the increased cost of primary energy products should both accelerate the rate of technological replacement and induce technological progress (Ruttan, 1997; Newell et al. 1999). Recent evidence (Popp, 2002) indicates that there is a significant relationship between energy prices and new innovation in energy-saving technologies. In addition, introducing carbon taxes compensated by a reduction of other distortionary taxes may yield a double dividend.

In this study we analyse the sectoral and macroeconomic impact of carbon taxes on the Russian economy and verify the double dividend hypothesis. According to our results, introducing carbon taxes compensated by a reduction in labour taxes can lead to a double dividend; however, welfare gains strongly depends on the labour supply elasticity as well as elasticities of substitution between labour and the capital-energy aggregate. This confirms conclusions made by Bosello et al. (2001), Capros et al. (1996), Carraro et al. (1996), and Sancho (2010). For example, under a perfectly inelastic supply of labour, the reduction of labour taxes would be fully absorbed by an increase in net wages. Therefore, the strong double dividend hypothesis fails. Moreover, according to our simulation results, the strong double dividend hypothesis fails, if labour and the capital-energy aggregate are assumed to be complements in production.

There are some limitations to this analysis. We do not consider distortions such as imperfect competitive market structures, which may significantly affect the results. For example, Böhringer et al. (2008) show that costs of environmental policy may be higher under an imperfect competitive market structure than under a perfect competitive market structure due to losses in economies of scale. However, there are only a few studies that regard the effects of carbon taxes on the economy under an imperfect competitive market structure.

Another limitation is that we use a static CGE model, which ignores dynamics of capital accumulations. Another important drawback to this analysis is that technological change, which would result from investment in energy efficiency, are also not captured in a static CGE model. Goulder and Schneider (1999) emphasise that the presence of price-induced technological change may imply lower costs of environmental policy.

The analysis does not include options for carbon permits trade. At the same time, a reduction in carbon emission will provide carbon permits, which can be sold in the international market, implying additional benefits of the environmental tax policy. For example, the level of carbon emissions in Russia was about 1556 million metric tons in 2009 (EIA, 2011). A reduction of carbon emissions by 10% may result in 1556 million euro, at the carbon price equals 10 euro per metric ton (ICE, 2011).

Finally, we do not consider the issue of income distributions since households are represented by a single private household. Income inequality is of high relevance for Russia. For instance, the Gini coefficient for Russia accounted to 0.42 in 2009 (FSSS, 2010), which indicates a relative high income inequality. On one hand, the poorest households would be affected more adversely by higher energy prices of energy commodities such as electricity, gas, and coal. This is because the expenditure shares of these energy commodities are larger by the poorest households compared to the richest households. In contrast, the expenditure share of petroleum products is larger by the richest households than by the poorest (Rutherford et al. 2004). On the other hand, carbon taxation leads to an increase in labour income compared to capital income and income from natural resources, where labour income is the main income source for the poorest households. For example, a CT_LT results in an increase in income from unskilled labour by 10.61%, from skilled labour it increases by 10.23%, from land it increases 1.15%, while income from capital and natural resources decrease by 3.77% and 3.66%, respectively.

References

ABARE (Australian Bureau of Agricultural and Resource Economics), 1996. The MEGABARE model: interim documentation.

APEC (Asia Pacific Energy Research Centre), 2006. APEC Energy Demand and Supply Outlook 2006. http://www.ieej.or.jp/aperc/outlook2006.html

Armington, P.S , 1969. A Theory of Demand for Products Distinguished by Place of Production. IMF Staff Paper 16, 159-178.

Bashmakov, I., 2009. Resource of energy efficiency in Russia: scale, costs, and benefits. Energy Efficiency 2(4), 369-386.

Bento, A.M, Jacobsen, M., 2007. Ricardian Rents, Environmental Policy and the 'Double-Dividend' Hypothesis. Journal of Environmental Economics and Management. 53 (2007) 17-31.

Böhringer, C., Löschel, A., Welsch, H., 2008. Environmental Taxation and Induced Structural Change in an Open Economy: The Role of Market Structure. German Economic Review 9(1), 17-40.

Bosello, F., Carraro, C., Galeotti, M., 2001. The Double Dividend Issue: Modelling Strategies and Empirical Findings. Environment and Development Economics 6(1), 9-45.

Bosquet, B., 2000. Environmental Tax Reform: Does it work? A Survey of the Empirical Evidence. Ecological Economics 34(1), 19-32.

Bovenberg, A., Goulder, L., 1996. Costs of Environmentally-Motivated Taxes in the Presence of other Taxes: General Equilibrium Analyses. National Tax Journal 50, 8.

Bovenberg, A., van der Ploeg, F., 1998. Consequences of Environmental Tax Reform for Unemployment and Welfare. Environmental and Resources Economics 12, 137-150.

Burniaux, J-M., Truong, T., 2002. GTAP-E: An Energy-Environmental Version of the GTAP Model. GTAP Technical Paper No.16.

Capros, P., Georgakopulos, P., Zografakis, S., Proost, S., van Regemorter, D., Conrad, K., Schmidt, T., Smeers, Y., Michiels, E., 1996. Double Dividend Analysis: First Results of a General Equilibrium Model (GEM-E3) Linking the EU-12 Countries. *Environmental Fiscal Reform and Unemployment*. Kluwe Academic, 1996.

Carraro, C., Soubeyran, A., 1996. Environmental Taxation and Employment in a Multi-Sector General Equilibrium Model. Environmental Fiscal Reform and Unemployment. Kluwe Academic, 1996.

Carraro, C., Galeotti, M., Gallo, M., 1996. Environmental Taxation and Unemployment: Some Evidence on the 'Double Dividend Hypothesis' in Europe. Journal of Public Economics 62(1-2), 141-181.

de Melo, J., Robinson, S., 1989. Product Differentiation and the Treatment of Foreign Trade in Computable General Equilibrium Models of Small Economies. Journal of International Economics 27, 47-67.

de Mooij, R., Bovenberg, A., 1998. Environmental Taxes, International Capital Mobility and Inefficient Tax Systems: Tax Burden vs. Tax Shifting. International Tax and Public Finance. 5(1), 7-39.

Devarajan, S., Lewis, J.D., Robinson, S., 1990. Policy Lessons from Trade-Focused, Two-Sector Models. Journal of Policy Modelling. 12, 625-657.

EIA (Energy Information Administration), 2011. International Energy Statistics. http://tonto.eia.doe.gov/cfapps/ipdbproject/iedindex3.cfm?tid=92&pid=47&aid=2&cid=CA,FR,GM,RS,US,&syid=2008&eyid=2008&unit=BTUPUSDP

ICE (Intercontinental Exchange), 2011. Emissions Report. https://www.theice.com/marketdata/reports/ReportCenter.shtml?reportId=83

Evers, M., Mooij, R., van Vuuren, D., 2008. The Wage Elasticity of Labour Supply: A Synthesis of Empirical Estimates. De Economist. 56, 25-43.

Federal Law No. 213-FZ from 24 Jul. 2009. http://base.consultant.ru/cons/cgi/online.cgi?req=doc;base=LAW;n=103301;dst=100353

FSSS – Federal State Statistics Service (2010). Social Economical Indicators of Poverty. http://www.gks.ru/wps/wcm/connect/rosstat/rosstatsite/main/publishing/catalog/statisticJournals/doc_1252310752594

Goulder, L., 1994. Environmental Taxation and the "Double-Dividend": A Reader's Guide. International Tax and Public Finance 2(2), 157-183.

Goulder, L., 2002. Environmental Policy Making in Economies with Prior Tax Distortion. Cheltenham; Northampton, Mass.: Elgar: 2002: XXIII.

Goulder, L., Schneider, S., 1999. Induced Technological Change and the Attractiveness of CO2 Abatement Policies. Resource and Energy Economics 21(3-4), 211-253.

GTAP, (2007). Version 7 of the GTAP database.

Jaffe, A., Newell, R., Stavins, R., 2004. Economics of Energy Efficiency. Encyclopaedia of Energy.

Lee, H-L., 2008. An Emissions Data Base fro Integrated Assessment of Climate Change Policy Using GTAP. https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=1143

Malcolm, G., 1998. Adjusting Tax Rates in the GTAP Data Base. GTAP Technical Paper No. 12.

McDonald, S., 2007. A Static Applied General Equilibrium Model: Technical Documentation. STAGE Version 1: July 2007. Course documentation.

McDonald, S., Thierfelder, K., 2004. Deriving a Global Social Accounting Matrix from GTAP Versions 5 and 6 Data. GTAP Technical Paper No. 22.

Mooij, R., 1996. Environmental Taxation and the Double Dividend. Kluwe Academic, 1996.

Newell, R., Jaffe, A., Stavins, R., 1999. The Induced Innovation Hypothesis and Energy-Saving Technological Change. Working Paper No. 6437.

Popp, D., 2002. Induced Innovation and Energy Prices. The American Economic Review 92(1).

Ruttan, V., 1997. Induced Innovation, Evolutionary Theory and Path Dependence: Sources of Technical Change. Economic Journal 107(1997): 1520-1529.

Sancho, F., 2010. Double Dividend Effectiveness of Energy Tax Policies and the Elasticity of Substitution: A CGE Appraisal. Energy Policy 38(6), 2927-2933.

UNFCCC (Unified Nations Framework, Convention on Climate Change), 2010. Fifth national communication. http://unfccc.int/national_reports/annex_i_natcom/submitted_natcom/items/4903.php

Varian, H., 1999. Grundzüge der Mikroökonomik. München; Wien: Oldenburg, 1999 (p. 244)

Veselov, F., Makarova, A., Khorshev, A., 2010. Impact of Restriction Measures for Greenhouse Gas Emission on Development of Electric Power Industry in Russia. International Journal of Low-Carbon Technologies. 5(4), 303-310.

WB (World Bank), 2008. Energy Efficiency in Russia: Untapped Reserves. Report. http://www.ifc.org/ifcext/rsefp.nsf/Content/Materials

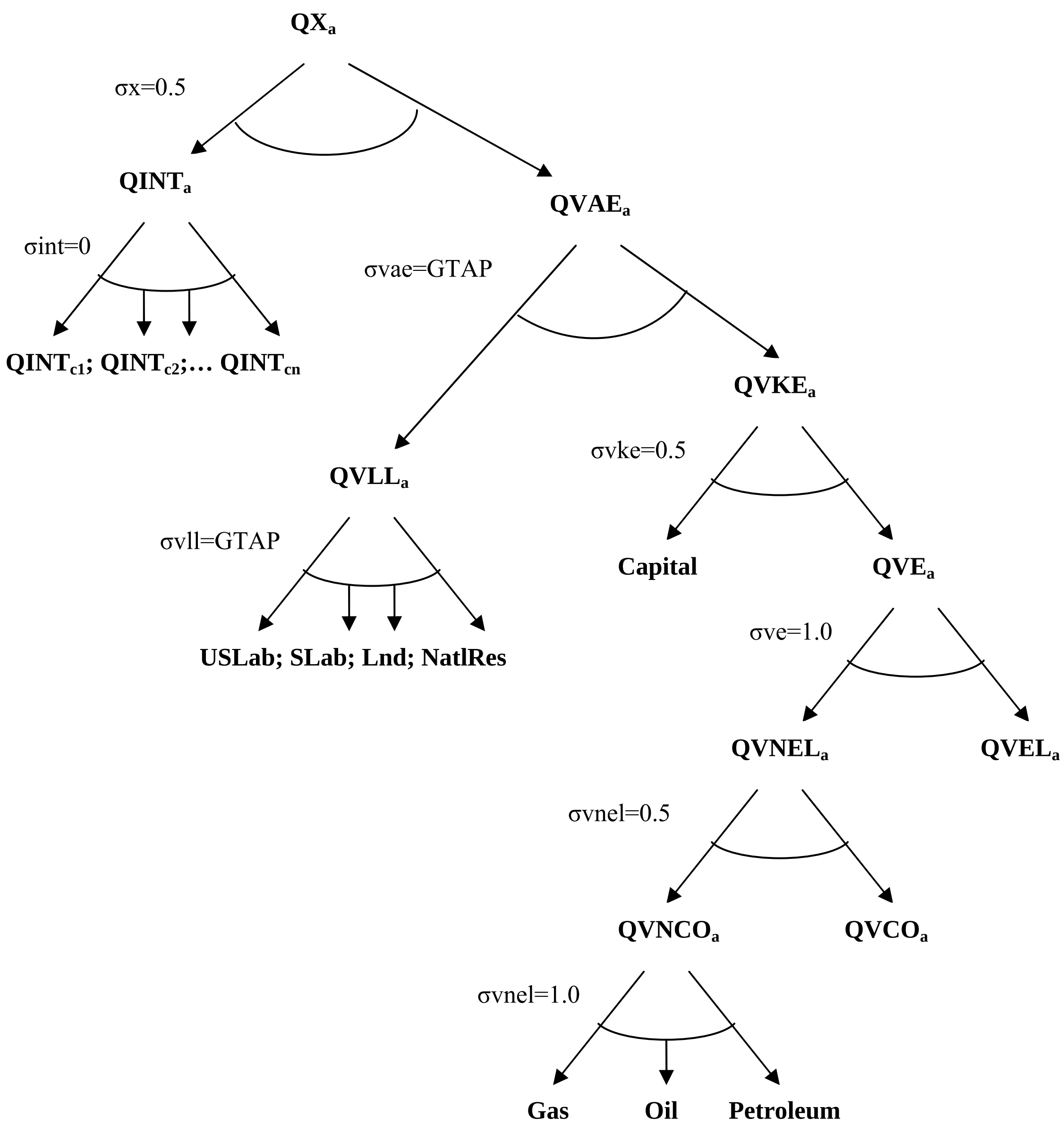
Annex

Annex A1: Formal Description of the Model Framework

Annex A1.1: Production System for Non-Energy Producing Sectors

The focus of this analysis is on production and consumption of energy commodities. Energy substitution is expected to be one of the important determinates of the effects of carbon taxes on the whole economy (Burniaux and Truong 2002). Therefore, we extend the standard version of the STAGE model by incorporating substitution possibilities between capital and energy inputs as well as substitution possibilities among energy inputs for non-energy producing sectors. Fig. 7.1 illustrates the modified nesting structure for non-energy producing sectors which consists of six levels. We use nested CES functions. One of the advantages of using nested CES functions is that an appropriate nesting structure can replicate any second order function (Perroni and Rutherford 1995).

Fig. 7.1 Modified nesting structure for non-energy producing sectors



Source: own compilation

For introduction of energy substitutions, we remove energy commodities, such as natural gas, gas manufacture, coal, crude oil, petroleum products, and electricity from intermediates to the value added composite. We use the sub-set $gtap_a$ and $leon_a$ for mapping sectors to different nesting structures. For instance, the sub-set $gtap_a$ includes all non-energy producing sectors, whereas the sub-set $leon_a$ includes energy producing sectors excluding the electricity sectors ($nely_a$). Using the sub-set $nely_a$ we exclude the electricity sector from the nesting structures since the electricity sector is modelled using a technology bundle approach. At the top level, the domestic output (QX_a) is defined by a two argument CES function over the aggregate of intermediates ($QINT_a$) and the aggregate of value added (QVA_a). Equation (a1.1.1) determinates the unit cost function for the activity price of total production (PX_a), where TX_a is a production tax. Equations (a1.1.2) and (a1.1.3) represent the corresponding demand functions for $QINT_a$ and $QVAE_a$, respectively.

Production Block – Top Level

(a1.1.1)	$PX_a * (1 - TX_a) = px\_ces_a$	$\forall a \in nely_a$
(a1.1.2)	$QINT_a = q\text{int}\_ces_a$	$\forall a \in nely_a$
(a1.1.3)	$QVAE_a = qvae\_ces_a$	$\forall a \in nely_a$

At the second level, the aggregate of value added-energy ($QVAE_a$) is specified as a two argument CES function over the aggregate of primary factors ($QVLL_a$) and the aggregate of capital-energy ($QVKE_a$). Equation (a1.1.4) determinates the unit cost function for the activity price of the value added-energy aggregate ($PVAE_a$). Equations (a1.1.5) and (a1.1.6) represent the corresponding demand functions for $QVKE_a$ and $QVLL_a$, respectively. Elasticities of substitution between primary factors and the capital-energy aggregate are taken from Version 7 of the GTAP database (see in Annex A2).

Production Block – Second Level

(a1.1.4)	$PVAE_a = pvae\_ces_a$	$\forall a \in nely_a$
(a1.1.5)	$QVKE_a = qvke\_ces_a$	$\forall a \in nely_a$
(a1.1.6)	$QVLL_a = qvll\_ces_a$	$\forall a \in nely_a$

As mentioned above, a use of macro functions can be quite convenient for changing the specification of CES functions. There are three cases: a standard CES function, a Cobb-Douglas function and a Leontief function. At each level of the production nest, it can be switched to another specification of CES function by changing macros. For example, the aggregate of value added-energy ($QVAE_a$) could be determinated as a Leontief or Cobb-Douglas function over the aggregate of primary factors ($QVLL_a$) and the aggregate of capital-energy ($QVKE_a$), by switching the macros equations as follows:

Production Block – Second Level (Alternative Formulations)

for a Leontief case:

$$PVAE_a = pvae\_leon_a \qquad \forall a \in nely_a$$

$$QVKE_a = qvke\_leon_a \quad \forall a \in nely_a$$

$$QVLL_a = qvll\_leon_a \quad \forall a \in nely_a$$

for a Cobb-Douglas case:

$$PVAE_a = pvae\_cd_a \quad \forall a \in nely_a$$

$$QVKE_a = qvke\_cd_a \quad \forall a \in nely_a$$

$$QVLL_a = qvll\_cd_a \quad \forall a \in nely_a$$

At the third level, the aggregate of primary factors ($QVLL_a$) is determinated by a standard CES function over primary factors, such as land, natural resources, skilled, and unskilled labour ($FD_{f,a}$). Land is used only by the agriculture sector, whereas natural resources are used by sectors such as agriculture, coal, crude oil, natural gas, and minerals. Equation (a1.1.7) determinates the unit cost function for the activity price of the primary factors aggregate ($PVLL_a$). Equation (a1.1.8) defines the corresponding demand functions for primary factors ($FD_{f,a}$). Elasticities of substitution among primary factors are taken from Version 7 of the GTAP database (see in Annex A2).

The aggregate of capital-energy ($QVKE_a$) is depicted by a two argument CES function over the aggregate of energy commodities (QVE_a) and capital ($FD_{fCap,a}$). Equation (a1.1.9) determinates the cost unit function for the activity price of capital-energy aggregate ($PVKE_a$). Equations (a1.1.10) and (a1.1.11) give the corresponding demand functions for QVE_a and $FD_{fCap,a}$, respectively. Elasticities of substitution between capital and the energy aggregate are assumed to equal 0.5, following Burniaux and Truong (2002).

Production Block for Non-Energy Producing Sectors – Third Level

(a1.1.7)	$PVLL_a = pvll\_ces_a$	$\forall a \in nely_a$ and $\forall a \in gtap_a$
(a1.1.8)	$FD_{f,a} = fd\_ces_{f,a}$	$\forall a \in nely_a$ and $\forall a \in gtap_a$ and $\forall a \in capn_f$
(a1.1.9)	$PVKE_a = pvke\_ces_a$	$\forall a \in nely_a$ and $\forall a \in gtap_a$
(a1.1.10)	$QVE_a = qve\_ces_a$	$\forall a \in nely_a$ and $\forall a \in gtap_a$
(a1.1.11)	$FD_{fCap,a} = fdcap\_ces_{fCap,a}$	$\forall a \in nely_a$ and $\forall a \in gtap_a$

The nesting structure of the energy aggregate is built based on the GTAP energy model (Burniaux and Truong 2002). At the fourth level, the aggregate of energy commodities (QVE_a) is specified as a Cobb-Douglas function over the aggregate of non-electric energy commodities ($QVNEL_a$) and electricity ($QVEL_a$). Equation (a1.1.12) defines the unit cost function for the activity price of the energy aggregate (PVE_a). Equations (a1.1.13) and (a1.1.14) determinate the corresponding demand functions for $QVEL_a$ and $QVNEL_a$, respectively. Equation (a1.1.15) gives the quantity identity for electricity demand ($QVEL_a$), whereas equation (a1.1.16) defines the price identity for electricity ($PVEL_a$).

Production Block for Non-Energy Producing Sectors – Fourth Level

(a1.1.12)	$PVE_a = pve\_cd_a$	$\forall a \in nely_a$ and $\forall a \in gtap_a$
(a1.1.13)	$QVEL_a = qvel\_cd_a$	$\forall a \in nely_a$ and $\forall a \in gtap_a$
(a1.1.14)	$QVNEL_a = qvnel\_cd_a$	$\forall a \in nely_a$ and $\forall a \in gtap_a$
(a1.1.15)	$QVEL_a = QINTD_{cely,a}$	$\forall a \in nely_a$ and $\forall a \in gtap_a$
(a1.1.16)	$PVEL_a = PQD_{cely}$	$\forall a \in nely_a$ and $\forall a \in gtap_a$

At the fifth level, the aggregate of non-electric energy commodities ($QVNEL_a$) is defined by a two argument CES function over the aggregate of non-coal energy commodities ($QVNCO_a$) and coal ($QVCO_a$). Equation (a1.1.17) determinates the unit cost function for the activity price of the non-electric aggregate ($PVNEL_a$). Equations (a1.1.18) and (a1.1.19) define the corresponding demand functions for $QVCO_a$ and $QVNCO_a$, respectively. Equations (a1.1.20) and (a1.1.21) represent the quantity and price identity for coal, where $TCARB_{ccoa,a}$ is the rate of carbon tax on coal. Elasticities of substitution between coal and non-coal energy commodities are assumed to equal 0.5, following Burniaux and Truong (2002).

Production Block for Non-Energy Producing Sectors – Fifth Level

(a1.1.17)	$PVNEL_a = pvnel\_ces_a$	$\forall a \in nely_a$ and $\forall a \in gtap_a$
(a1.1.18)	$QVCO_a = qvcon\_ces_a$	$\forall a \in nely_a$ and $\forall a \in gtap_a$
(a1.1.19)	$QVNCO_a = qvnvo\_ces_a$	$\forall a \in nely_a$ and $\forall a \in gtap_a$
(a1.1.20)	$QVCO_a = QINTD_{ccoa,a}$	$\forall a \in nely_a$ and $\forall a \in gtap_a$
(a1.1.21)	$PVCO_a = PQD_{ccoa} + TCARB_{ccoa,a}$	$\forall a \in nely_a$ and $\forall a \in gtap_a$

Finally, the aggregate of non-coal energy commodities ($QVNCO_a$) is specified as a Cobb-Douglas function over energy commodities ($QINTD_{c,a}$), such as natural gas, gas manufacture, crude oil, and petroleum products. Equation (a1.1.22) determinates the unit cost function for the activity price of the non-coal aggregates ($PVNCO_a$). Equation (a1.1.23) defines the corresponding demand function for natural gas, gas manufacture, crude oil, and petroleum products.

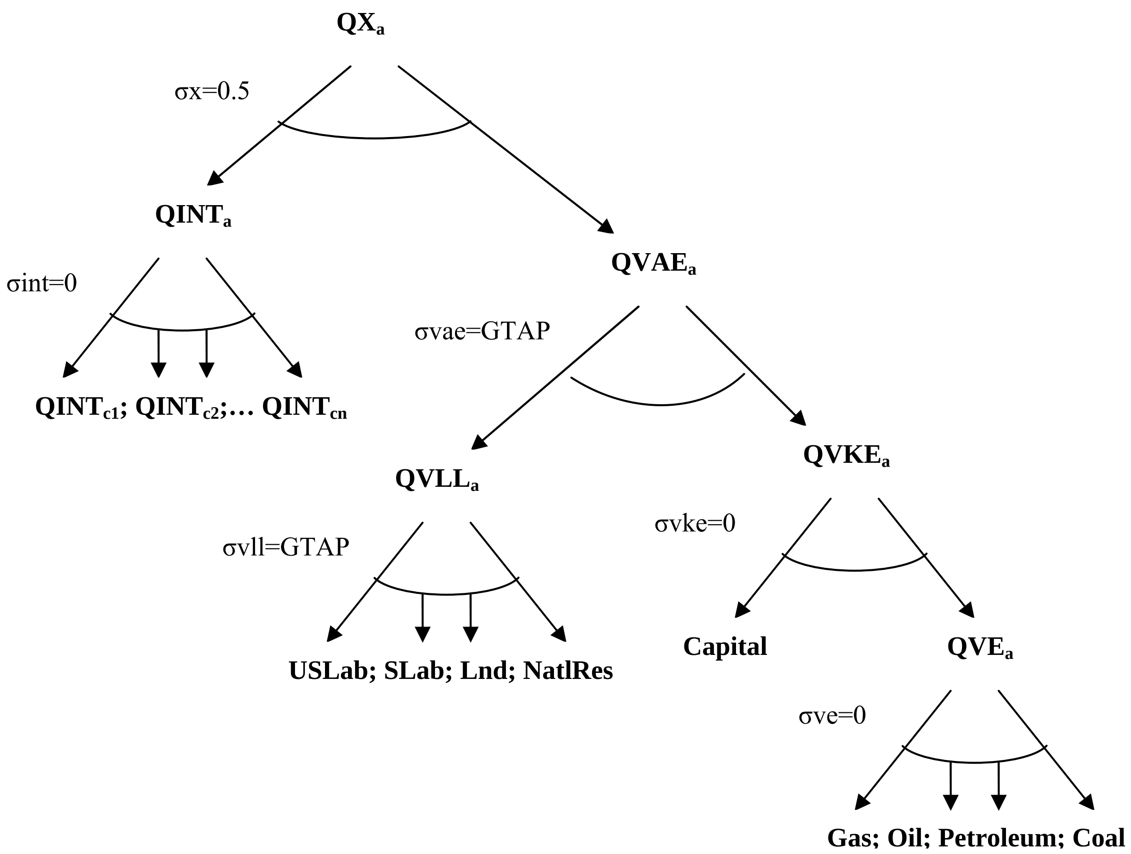
Production Block for Non-Energy Producing Sectors – Sixth Level

(a1.1.22)	$PVNCO_a = pvnco\_cd_a$	$\forall a \in nely_a$ and $\forall a \in gtap_a$
(a1.1.23)	$QINTD_{c,a} = q\text{int}d\_cd_{c,a}$	$\forall a \in nely_a$ and $\forall a \in gtap_a$

Annex A1.2: Production System for Energy Producing Sectors

The energy producing sectors such as crude oil, coal, natural gas, and petroleum products are not assumed having any substitution possibilities between capital and energy commodities as well as among energy commodities. Such an assumption is made to limit elasticities of supply of energies. Elasticities of supply of energies are crucial for an energy environmental analysis (Burniaux and Truong 2002). Fig. 7.2 illustrates the nesting structure for energy producing sectors.

Fig. 7.2 Nesting structure for energy producing sectors



Source: own compilation

The first two levels of the nesting structure for energy producing sectors are identical with those for non-energy producing sectors. At the third level, the aggregate of capital-energy ($QVKE_a$) is depicted by a Leontief function over energy inputs used by energy producing sectors. Equation (a1.2.1) determinates the unit cost function for the activity price of the capital-energy aggregate ($PVKE_a$), where equations (a1.2.2) and (a1.2.3) are the corresponding demand functions for QVE_a and $FD_{fCap,a.}$, respectively.

Production Block for Energy Producing Sectors – Third Level

(a1.2.1)	$PVKE_a = pvke\_leon_a$	$\forall a \in nely_a$ and $\forall a \in leon_a$
(a1.2.2)	$QVE_a = qve\_leon_a$	$\forall a \in nely_a$ and $\forall a \in leon_a$
(a1.2.3)	$FD_{fCap,a} = fdcap\_leon_{fCap,a}$	$\forall a \in nely_a$ and $\forall a \in leon_a$

At the fourth lever, the aggregate of energy commodities (QVE_a) for energy producing sectors is determinated by a Leontief function. Equation (a1.2.4) determinates the unit cost function for the activity price of the energy aggregate (PVE_a), where equation (a1.2.5) gives the corresponding demand functions for energy inputs ($QINTD_{c,a}$).

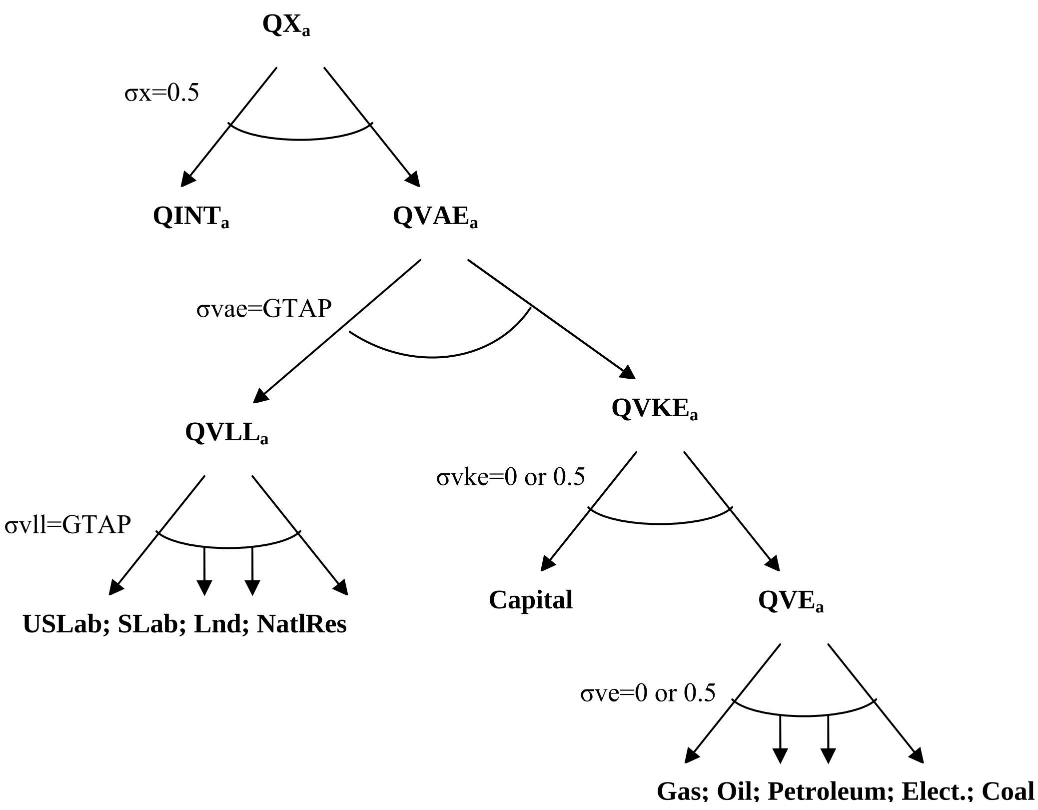
Production Block for Energy Producing Sectors – Fourth Level

(a1.2.4)	$PVE_a = pve\_leon_a$	$\forall a \in nely_a$ and $\forall a \in leon_a$
(a1.2.5)	$QINTD_{c,a} = q\,\mathrm{int}\,d\_leon_{c,a}$	$\forall a \in nely_a$ and $\forall a \in leon_a$ and $\forall c \in ceg_c$

Annex A1.3: Alternative Nesting Structures for Non-Energy Producing Sectors

Substitutions between capital and energy commodities as well as energy commodities are expected to be crucial for our analysis. Therefore, for sensitivity analysis we consider an extreme case, where capital and the energy aggregate are treated as complements, which are specified by a Leontief function. Fig. 7.3 illustrates the alternative nesting structure for non-energy producing sectors without capital-energy substitutions.

Fig. 7.3 Alternative nesting structure for non-energy producing sectors



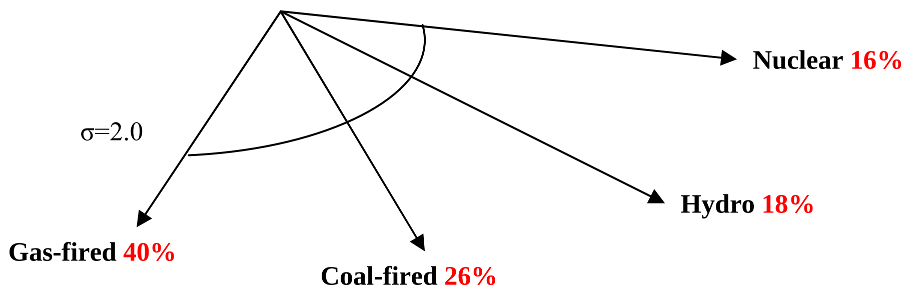
Source: own compilation

Moreover, we consider two options regarding nesting structures of the energy aggregate for non-energy producing sectors: CES and Leontief nesting structures (Fig. 7.3). Under the CES nesting structure, the energy aggregate is specified by a CES function over all energy inputs. In contrast, the Leontief nesting structure does not allow any substitution possibilities among energy commodities, which are depicted using a Leontief function.

Annex A1.4: Modelling the Power Generation Sector

The power generation sector is the largest domestic consumer of coal and gas as well as a large consumer of petroleum products. An explicit design of the power generation sector is expected to be crucial for an analysis of an environment policy reform. We disaggregate the electricity generation sector into four power generation technologies: coal-fired, gas-fired, nuclear technologies and hydro technologies (Fig. 7.4). The disaggregation is based on output shares and factor intensities by technologies. For instance, gas-fired technologies produce 40% of the total electricity, coal-fired technologies (26%), hydro (18%), and nuclear (16%) (EIA 2011; APEC 2006). Relative factor intensities are calculated based on data on costs and performance of electricity generation technologies provided by the Organisation of Economic Co-operation and Development (OECD) (Veselov et al. 2010). For instance, we find that coal-fired technologies are 24% less capital intensive compared to nuclear and hydro technologies, whereas gas-fired technologies are 88% less capital intensive than hydro and nuclear technologies. Due to lack of information, we assume that labour intensities would be equal among all technologies. Moreover, it is assumed that nuclear and hydro technologies face the same factor intensity.

Fig. 7.4 Structure of the power generation sector



Source: own compilation

The modelling of electricity generation technologies is based on a technology bundle approach, which is, for example, applied in the MEGABARE model (ABARE 1996). All power generation technologies are assumed to be substitutes and are depicted using a standard CES function. Elasticities of substitution among technologies are assumed to equal 2.0. The equation block of the production nesting for the electricity technologies is derived using the dual approach, where the equations are coded using macro functions. Equation (a1.4.1) defines the unit cost function for the activity price of electricity (PX_a), where TX_a is a production tax on electricity. Equation (a1.4.2) represents the corresponding demand function for output from different electricity generation technologies ($QXtb_{a,tb}$). The macros are listed in Annex A1.6.

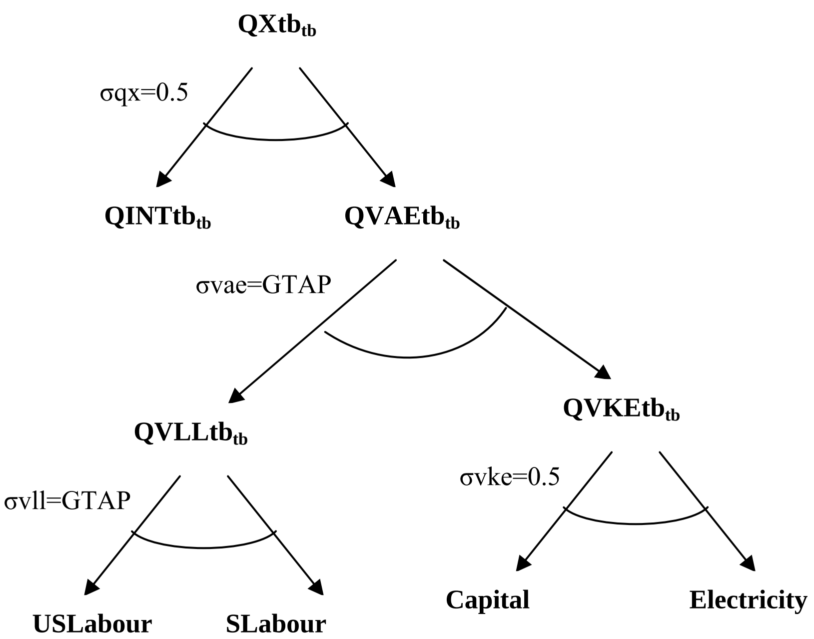
Technology Bundle for the Power Generation Sector

(a1.4.1)	$PX_a * (1 - TX_a) = pxe\_ces_a$	$\forall a \in ely_a$
(a1.4.2)	$QXtb_{a,tb} = qxtb\_ces_{a,tb}$	$\forall a \in ely_a$

It is necessary to introduce a CES function within the power generation technologies to avoid an unrealistic large switch from one technology to another. In the MEGABARE model, however, electricity technologies are modelled using a CRASH function. The CRASH function is identical to a CES function, yet it applies different elasticities of substitution among technologies. Furthermore, in the MEGABARE model each technology is described by a Leontief function, which implies no substitutions among primary factors as well as intermediates.

In contrast, we assume some substitution possibilities within the production structures for all technologies. In particular, each power generation technology is described by a nested production structure, which is similar with the nesting structure for non-energy producing sectors (Fig. 7.2). Moreover, we use the same elasticities of substitution among primary factors as is used in other sectors. Fig. 7.5 illustrates the nesting structure for nuclear and hydro generation technologies.

Fig.7.5 Nesting structure for nuclear and hydro generation technologies



Source: own compilation

The first four levels of the nesting structure are identical for all electricity technologies. At the top level, electricity is produced by each technology (QXtb) using the aggregate of intermediates (QINTtb) and the aggregate of value added-energy (QVAEtb). The substitution possibility between the *QINTtb* and *QVAEtb* aggregates is depicted by a two argument CES function. Equation (a1.4.3) determinates the unit cost function for the activity price for electricity technologies (PXtb), where equations (a1.4.4) and (a1.4.5) are the corresponding demand functions for *QVAEtb* and *QINTtb,* respectively. Equation (a1.4.6) defines the price identity for intermediate prices for electricity technologies.

Production Block for Electricity Technologies – Top Level

(a1.4.3)	$PXtb_{a,tb} = pxtb\_ces_{a,tb}$	$\forall a \in ely_a$
(a1.4.4)	$QVAEtb_{a,tb} = qvaetb\_ces_{a,tb}$	$\forall a \in ely_a$
(a1.4.5)	$QINTtb_{a,tb} = q\,\text{int}\,tb\_ces_{a,tb}$	$\forall a \in ely_a$
(a1.4.6)	$PINTtb_{a,tb} = PINT_a$	$\forall a \in ely_a$

At the second level, the aggregate of value added-energy by technologies (QVAEtb) is specified as a two argument CES function over the aggregate of labour (QVLLtb) and the aggregate of capital-energy (QVKEtb). Equation (a1.4.7) determinates the unit cost function for the activity price of the value added-energy aggregate (PVAEtb), where equations (a1.4.8) and (a1.4.9) are the corresponding demand functions *QVLLtb* and *QVKEtb*, respectively.

Production Block for Electricity Technologies – Second Level

(a1.4.7)	$PVAEtb_{a,tb} = pvaetb\_ces_{a,tb}$	$\forall a \in ely_a$
(a1.4.8)	$QVLLtb_{a,tb} = qvlltb\_ces_{a,tb}$	$\forall a \in ely_a$
(a1.4.9)	$QVKEtb_{a,tb} = qvketb\_ces_{a,tb}$	$\forall a \in ely_a$

At the third level, the aggregate of labour is defined as a two argument CES function over skilled and unskilled labour ($FDtb_f$) since land is used only by the agriculture sector, whereas natural resources are used by sectors, such as agriculture, coal, crude oil, natural gas, and minerals. Equation (a1.4.10) determinates the unit cost function for the activity price of the labour aggregate (PVLLtb), where equation (a1.4.11) defines the corresponding demand function for *FDtb*.

Production Block for Electricity Technologies – Third Level

(a1.4.10)	$PVLLtb_{a,tb} = pvlltb\_ces_{a,tb}$	$\forall a \in ely_a$
(a1.4.11)	$FDtb_{f,a,tb} = fdtb\_ces_{f,a,tb}$	$\forall a \in ely_a$

The aggregate of capital-energy (QVKEtb) is determinated as a two argument CES function over capital ($FDtb_{Cap}$) and the energy composite (QVEtb), where the energy composite for hydro and nuclear technologies are represented by electricity only. Equation (a1.4.12) determinates the unit cost function for the activity price of the capital-energy aggregate (PVKEtb), where equations (a1.4.13) and (a1.4.14) define the corresponding functions for

$FDtb_{Cap}$ and *QVEtb,* respectively. For hydro and nuclear technologies, equations (a1.4.15) and (a1.4.16) represent the quantity and price identity of demand for electricity by technologies.

Production Block for Electricity Technologies – Third Level

(a1.4.12) $PVKEtb_{a,tb} = pvketb\_ces_{a,tb}$ $\forall a \in ely_a$

(a1.4.13) $FDtb_{fCap,a,tb} = fdtbke\_ces_{fCap,a,tb}$ $\forall a \in ely_a$

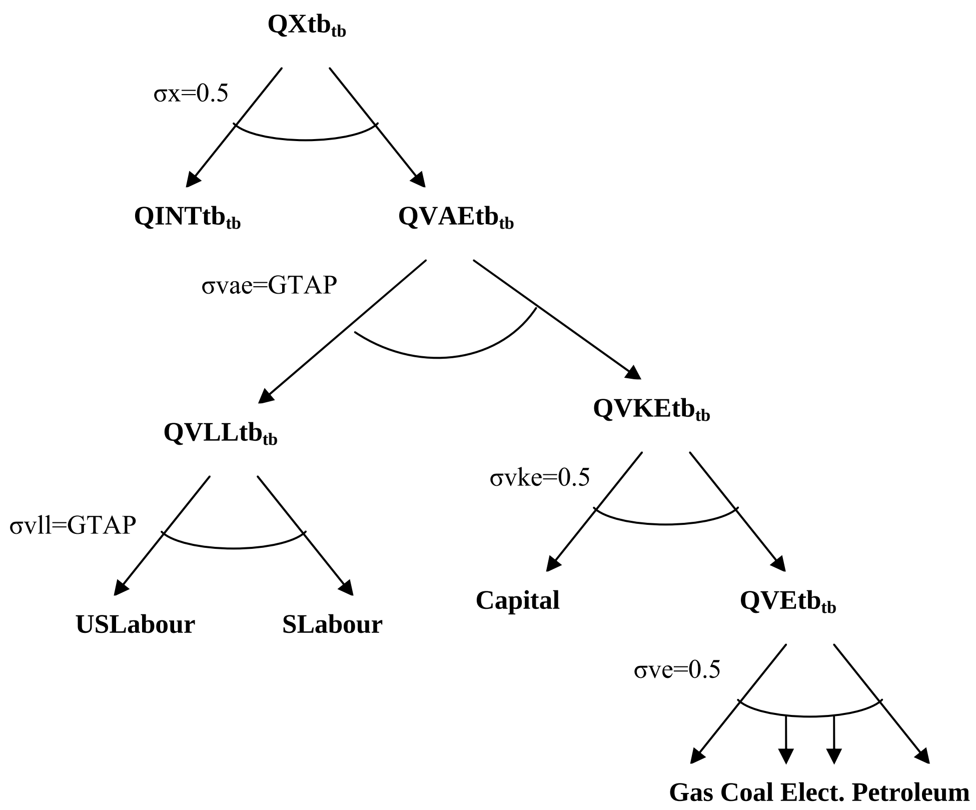
(a1.4.14) $QVEtb_{a,tb} = qvetb\_ces_{a,tb}$ $\forall a \in ely_a$

(a1.4.15) $QVEtb_{a,tb} = QINTDtb_{cely,a,tb}$ $\forall a \in ely_a$ and $c \in ceg_c$ and $tb \in thern_{tb}$

(a1.4.16) $PVEtb_{a,tb} = PQD_{cely}$ $\forall a \in ely_a$ and $tb \in thern_{tb}$

For coal-fired and gas-fired technologies, the production structure consists of four levels, where the last level represents an aggregate of energy inputs (QVEtb). Fig. 7.6 shows the production structure of gas- and coal-fired power generation technologies.

Fig. 7.6 Nesting structure for gas- and coal-fired power generation technologies



Source: own compilation

Within gas-fired technologies, the energy composite (QVEtb) is specified as a two argument CES function over natural gas and gas manufacture (QINTDtb). For coal-fired technologies it is a standard CES function over coal, crude oil and petroleum products (QINTDtb). Equation (a1.4.17) determinates the unit cost function for the activity price of the energy aggregate (PVEtb), where equation (a1.4.18) specifies the corresponding demand functions for energy inputs by thermal technologies.

Production Block for Coal-and Gas-fired Technologies – Fourth Level

---

(a1.4.17) $PVEtb_{a,tb} = pvetb\_ces_{a,tb}$ $\forall a \in ely_a$

(a1.4.18) $QINTDtb_{c,a,tb} = q\,\text{int}\,dtb\_ces_{c,a,tb}$ $\forall a \in ely_a$

Equations (a1.4.19), (a1.4.20) and (a1.4.21) define the quantity identity of demand for primary factors (FDtb), intermediate (QINTtb) and energy inputs (QINTDtb), respectively, which are a sum over primary factor as well as intermediate demand over all technologies.

Quantity Identities for the Power Generation Sector

(a1.4.19) $FD_{f,a} = \sum_{tb} FDtb_{f,a,tb}$ $\forall a \in ely_a$

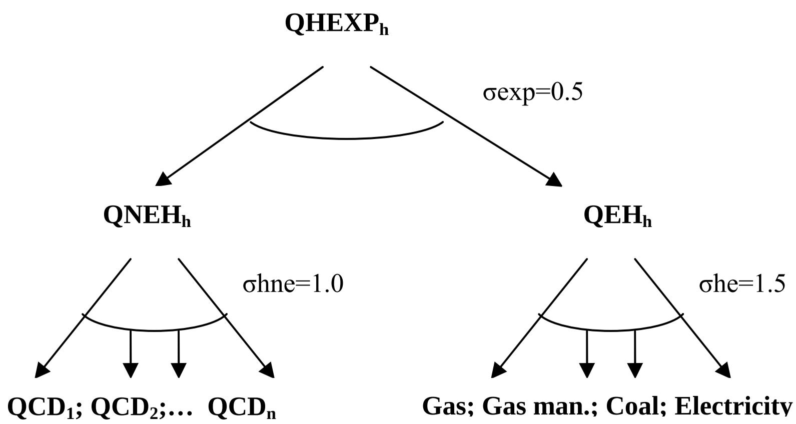
(a1.4.20) $QINT_a = \sum_{tb} QINTtb_{a,tb}$ $\forall a \in ely_a$

(a1.4.21) $QINTD_{c,a} = \sum_{tb} QINTDtb_{c,a,tb}$ $\forall a \in ely_a$

Annex A1.5: Structure of Household Demand

In the standard STAGE model, the household demand function is derived from a Stone-Geary utility function. The main features of such a demand function are linearity in prices and income. Moreover, in the presence of subsistence consumption, income elasticities are not unity; however, the marginal budget shares are constant, implying a straightforward Engel's curve. For our analysis we introduce a nested linear expenditure system for household consumption, which is quiet similar with the government demand system in the GTAP energy model (Burniaux and Truong 2002). Fig. 7.6 illustrates the household demand system in the modified version of the STAGE model.

Fig. 7.6 Household demand system



Source: own compilation

The top level is depicted by a CES function, which describes a substitution possibility between the energy composite (QEH_h) and the non-energy composite ($QNEH_h$). Elasticities of substitution are assumed to equal 0.5. The household demand system is derived using dual approach. Moreover, we use macro functions for determination price indices and corresponding demand functions. Equation (a1.4.1) determinates the price index of the total household consumption ($PHEXP_h$). Equation (a1.4.2) and (a1.4.3) represents the corresponding demand functions for the energy composite (QEH_h) and the non-energy composite ($QNEH_h$) including petroleum products.

Household Consumption: Top Level

(a1.5.1) $PHEXP_h = ph\exp\_ces_h$

(a1.5.2) $QEH_h = qeh\_ces_h$

(a1.5.3) $QNEH_h = qneh\_ces_h$

At the second level, the composite of energy commodities (QEH_h) is a standard CES function over energy commodities, such as natural gas, gas manufacture, coal, and electricity. The elasticity of substitution among energy commodities is assumed to equal 1.5. A CES formulation of the energy composite reflects high substitution possibilities among energy commodities regarding heating purposes. Crude oil is not consumed by households. Moreover, petroleum products are excluded from the energy composite since elasticities of substitution between petroleum products and other energy commodities are expected to be small. Equation (a1.4.4) determinates the price index of the energy composite (PEH_h), where equation (a1.4.5) defines the corresponding demand function for energy commodities ($QCDhe_{c,h}$).

Household Consumption: Second Level

(a1.5.4)	$PEH_h = qeh\_ces_h$	
(a1.5.5)	$QCDhe_{c,h} = qcd\_ces_{c,h}$	$\forall c \in he_c$
(a1.5.6)	$PNEH_h = qneh\_cd_h$	
(a1.5.7)	$QCDhne_{c,h} = qcd\_cd_{c,h}$	$\forall c \in hne_c$
(a1.5.8)	$QHEXP_h * PHEXP_h = HEXP_h - \sum_c qcdconst_{c,h}(PQD_c + TCARBH_{c,h})$	
(a1.5.9)	$QCD_{c,h} = qcdconst_{c,h} + QCDhe_{c,h}$	$\forall c \in he_c$
(a1.5.10)	$QCD_{c,h} = qcdconst_{c,h} + QCDhne_{c,h}$	$\forall c \in hne_c$

The composite of non-energy commodities ($QNEH_h$) is determined by a Cobb-Douglas function over non-energy commodities including petroleum products. Demand for energy and non-energy commodities consumed by households is differentiated using a sub-set he_c and hne_c, respectively. Equation (a1.4.6) defines the price index of the non-energy composite ($PNEH_h$), where equation (a1.4.7) specifies the corresponding demand function for non-energy commodities ($QCDhne_{c,h}$). Equation (a1.4.8) represents the income balance for household consumption. Equation (a1.4.9) and (a1.4.10) determinate the total household consumption, which consists of subsistence consumption ($qcdconst_{c,h}$) and superior consumption of the energy ($QCDhe_{c,h}$) and non-energy composites ($QCDhne_{c,h}$). The level of subsistence consumption for all commodities is assumed to equal 70% of the initial consumption level which is provided in the database.

Annex A1.6: Corresponding Macro Functions

Macros for Non-Energy Producing Sectors

```
*       Top Level
$macro   px_ces(a)       (1/ADX(a))*(deltaqx(a)**elx(a)*PVAE(a)**(1-elx(a)) + (1-deltaqx(a))**elx(a)*PINT(a)**(1-elx(a)))**(1/(1-elx(a)))
$macro   qvae_ces(a)   (QX(a)/ADX(a))*(ADX(a)*deltaqx(a)*PX(a)*(1-TX(a))/PVAE(a))**elx(a)
$macro   qint_ces(a)     (QX(a)/ADX(a))*(ADX(a)*(1-deltaqx(a))*PX(a)*(1-TX(a))/PINT(a))**elx(a)

*       Second Level: two argument CES formulation
$macro   pvae_ces(a)    (1/ADVAE(a))*(deltavae(a)**elvae(a)*PVKE(a)**(1-elvae(a))  + (1-deltavae(a))**elvae(a)*PVLL(a)**(1-elvae(a)))**(1/(1-elvae(a)))
$macro   qvke_ces(a)    (QVAE(a)/ADVAE(a))*(ADVAE(a)*deltavae(a)*PVAE(a)/PVKE(a))**elvae(a)
$macro   qvll_ces(a)      (QVAE(a)/ADVAE(a))*(ADVAE(a)*(1-deltavae(a))*PVAE(a)/PVLL(a))**elvae(a)

*       Second Level: Leontief formulation
$macro   pvae_leo(a)      (PVKE(a)*QVKE(a) + PVLL(a)*QVLL(a))/QVAE(a)
$macro   qvke_leo(a)      ioqvke(a)*QVAE(a)
$macro   qvll_leo(a)       ioqvll(a)*QVAE(a)

*       Third Level
$macro   pvll_ces(a)       (1/ADVLL(a))*SUM(f$deltavll(f,a), deltavll(f,a)**elvll(a)*(WF(f)*WFDIST(f,a)*(1+TF(f,a)))**(1-elvll(a)))**(1/(1-elvll(a)))
$macro   fdvll_ces(f,a)   (QVLL(a)/ADVLL(a))*(ADVLL(a)*deltavll(f,a)*PVLL(a)/(WF(f)*WFDIST(f,a)*(1+TF(f,a))))**elvll(a)

*       Third Level
$macro   pvke_ces(a)      (1/ADVKE(a))*(deltavke(a)**elvke(a)*PVE(a)**(1-elvke(a))  + (1-deltavke(a))**elvke(a)*(WF("fCap")*WFDIST("fCap",a)*(1 + TF("fCap",a)))**(1-
elvke(a)))**(1/(1-elvke(a)))
$macro   qve_ces(a)        (QVKE(a)/ADVKE(a))*(ADVKE(a)*deltavke(a)*PVKE(a)/PVE(a))**elvke(a)
$macro   fdcap_ces(a)     (QVKE(a)/ADVKE(a))*(ADVKE(a)*(1-deltavke(a))*PVKE(a)/(WF("fCap")*WFDIST("fCap",a)*(1+TF("fCap",a))))**elvke(a)

*          Fourth Level
$macro   pve_cd(a)        (1/adve(a))*(PVEL(a)/rhocel(a))**rhocel(a)*(PVNEL(a)/rhocnel(a))**rhocnel(a)
$macro   qvel_cd(a)        rhocel(a)*QVE(a)*PVE(a)/PVEL(a)
$macro   qvnel_cd(a)      rhocnel(a)*PVE(a)*QVE(a)/PVNEL(a)

*          Fifth Level
$macro   pvnel_ces(a)     (1/adnel(a))*(deltanel(a)**elnel(a)*PVCO(a)**(1-elnel(a)) + (1-deltanel(a))**elnel(a)*PVNCO(a)**(1-elnel(a)))**(1/(1-elnel(a)))
$macro   qvco_ces(a)      (QVNEL(a)/adnel(a))*(adnel(a)*deltanel(a)*PVNEL(a)/PVCO(a))**elnel(a)
$macro   qvnco_ces(a)     (QVNEL(a)/adnel(a))*(adnel(a)*(1-deltanel(a))*PVNEL(a)/PVNCO(a))**elnel(a)
```

```
*       Sixth Level
$macro  pvnco_cd(a)     (1/adnco(a))*prod(c$coaln(c), ((PQD(c)*(1+TEG(c,a))*PQDDIST(c,a) + TCARB(c,a))/rhocnco(c,a))**rhocnco(c,a))
$macro  qintd_cd(c,a)   rhocnco(c,a)*QVNCO(a)*PVNCO(a)/(PQD(c)*(1+TEG(c,a))*PQDDIST(c,a) + TCARB(c,a))
```

Macros for Energy Producing Sectors

```
*     Third Level
$macro  pvke_leo(a)     (QVE(a)*PVE(a)+ FD("fCap",a)*WF("fCap")*WFDIST("fCap",a)*(1+TF("fCap",a)))/QVKE(a)
$macro  qve_leo(a)      ioqve(a)*QVKE(a)
$macro  fdcap_leo(a)    ioqcap(a)*QVKE(a)

*     Fourth Level
$macro  pve_leo(a)      SUM(c$ceg(c), ((PQD(c) + TCARB(c,a))*(QINTD(c,a)))/QVE(a)
$macro  qintd_leo(c,a)  ioqenergy(c,a)*QVE(a)
```

Macros for the Electricity Sector

```
*     Power Generation Technologies
$macro  pxe_ces(a)      (1/adtb(a))*sum(tb, deltatb(a,tb)**eltb*PXtb(a,tb)**(1-eltb))**(1/(1-eltb))
$macro  qxtb_ces(a,tb)  (QX(a)/adtb(a))*(adtb(a)*deltatb(a,tb)*(PX(a)*(1-TX(a)))/PXtb(a,tb))**eltb

*     Top Level
$macro  pxtb_ces(a,tb)     (1/atbx(a,tb))*(dtbx(a,tb)**eltbx*PVAEtb(a,tb)**(1-eltbx) + (1-dtbx(a,tb))**eltbx*PINTtb(a,tb)**(1-eltbx))**(1/(1-eltbx))
$macro  qvaetb_ces(a,tb)  (QXtb(a,tb)/atbx(a,tb))*(atbx(a,tb)*dtbx(a,tb)*PXtb(a,tb)/PVAEtb(a,tb))**eltbx
$macro  qinttb_ces(a,tb)   (QXtb(a,tb)/atbx(a,tb))*(atbx(a,tb)*(1-dtbx(a,tb))*PXtb(a,tb)/PINTtb(a,tb))**eltbx

*     Second Level
$macro  pvaetb_ces(a,tb)  (1/atbvae(a,tb))*(dtbvae(a,tb)**eltbvae*PVLLtb(a,tb)**(1-eltbvae) + (1-dtbvae(a,tb))**eltbvae*PVKEtb(a,tb)**(1-eltbvae))**(1/(1-eltbvae))
$macro  qvlltb_ces(a,tb)   (QVAEtb(a,tb)/atbvae(a,tb))*(atbvae(a,tb)*dtbvae(a,tb)*PVAEtb(a,tb)/PVLLtb(a,tb))**eltbvae
$macro  qvketb_ces(a,tb)  (QVAEtb(a,tb)/atbvae(a,tb))*(atbvae(a,tb)*(1-dtbvae(a,tb))*PVAEtb(a,tb)/PVKEtb(a,tb))**eltbvae

*     Third Level
$macro  pvlltb_ces(a,tb)   (1/atbvll(a,tb))*sum(f$(capn(f) and dtbvll(f,a,tb)), dtbvll(f,a,tb)**eltbvll*(WF(f)*WFDIST(f,a)*(1+TF(f,a)))**(1-eltbvll))**(1/(1-eltbvll))
$macro  fdtb_ces(f,a,tb)   (QVLLtb(a,tb)/atbvll(a,tb))*(atbvll(a,tb)*dtbvll(f,a,tb)*PVLLtb(a,tb)/(WF(f)*WFDIST(f,a)*(1+TF(f,a))))**eltbvll

*     Third Level
```

```
$macro  pvketb_ces(a,tb)   (1/atbvke(a,tb))*(dtbvke(a,tb)**eltbke*(WF("fCap")*WFDIST("fCap",a)*(1+TF("fCap",a)))**(1-eltbke) + (1-
dtbvke(a,tb))**eltbke*PVEtb(a,tb)**(1-eltbke))**(1/(1-eltbke))
$macro  fdtbke_ces(f,a,tb)  (QVKEtb(a,tb)/atbvke(a,tb))*(atbvke(a,tb)*dtbvke(a,tb)*PVKEtb(a,tb)/(WF("fCap")*WFDIST("fCap",a)*(1+TF("fCap",a))))**eltbke
$macro  qvetb_ces(a,tb)    (QVKEtb(a,tb)/atbvke(a,tb))*(atbvke(a,tb)*(1-dtbvke(a,tb))*PVKEtb(a,tb)/PVEtb(a,tb))**eltbke

*     Fourth Level for gas- and coal-fired technologies
$macro  pvetb_ces(a,tb)      (1/atbve(a,tb))*sum(c$ceg(c), dtbve(c,a,tb)**eltbve*((PQD(c) + TCARB(c,a))**(1-eltbve))**(1/(1-eltbve))
$macro  qintdtb_ces(c,a,tb)  (QVEtb(a,tb)/atbve(a,tb))*(atbve(a,tb)*dtbve(c,a,tb)*PVEtb(a,tb)/((PQD(c)  + TCARB(c,a)))**eltbve
```

Household Demand

```
*     Top level
$macro  phexp_ces(h)  (1/ach(h))*(deltah(h)**elasth(h)*PEH(h)**(1-elasth(h)) + (1-deltah(h))**elasth(h)*PNEH(h)**(1-elasth(h)))**(1/(1-elasth(h)))
$macro  qeh_ces(h)    (QHEXP(h)/ach(h))*(ach(h)*deltah(h)*PHEXP(h)/PEH(h))**(1/(1+rhoch(h)))
$macro  qneh_ces(h)   (QHEXP(h)/ach(h))*(ach(h)*(1-deltah(h))*PHEXP(h)/PNEH(h))**(1/(1+rhoch(h)))

*     Second level
$macro  peh_ces(h)       (1/aceh2(h))*sum(c$he(c), deltaeh(c,h)**elasteh(h)*(PQD(c) + TCARBH(c,h))**(1-elasteh(h)))**(1/(1-elasteh(h)))
$macro  qcdhe_ces(c,h)  (QEH(h)/aceh2(h))*(aceh2(h)*deltaeh(c,h)*PEH(h)/(PQD(c) + TCARBH(c,h)))**(1/(1+rhoceh(h)))

*     Second level
$macro  pneh_cd(h)     (1/acneh(h))*prod(c$hne(c),((PQD(c) + TCARBH(c,h))/comhav(c,h))**comhav(c,h))
$macro  qcdhne_cd(h)   comhav(c,h)*QNEH(h)*PNEH(h)/(PQD(c) + TCARBH(c,h))
```

World Demand for Natural Gas

```
*     CES function for world import demand
$macro  pet_ces(c)    (1/atw(c))*(deltw(c)**elwimp(c)*PWE(c)**(1-elwimp(c)) + (1-deltw(c))**elwimp(c)*PER(c)**(1-elwimp(c)))**(1/(1-elwimp(c)))
$macro  qe_ces(c)     (QET(c)/atw(c))*(atw(c)*deltw(c)*PET(c)/PWE(c))**elwimp(c)
$macro  qer_ces(c)    (QET(c)/atw(c))*(atw(c)*(1-deltw(c))*PET(c)/PER(c))**elwimp(c)
```

Annex A2: Elasticities in the Model

Table A2 Armington elasticities, CET elasticities, and elasticities of substitution among primary factors

	Armington elasticities	**CET elasticities**	**Elasticities of substitution among primary factors**
Agriculture	1.45	1.50	0.22
Coal	1.52	0.50	0.20
Crude oil	2.60	3.00	0.20
Natural gas	8.60	3.00	0.20
Minerals	0.45	1.50	0.20
Food products	1.47	0.75	1.12
Textile products	1.91	1.50	1.26
Wood products	1.70	3.00	1.26
Paper products	1.47	1.50	1.26
Petroleum products	1.05	3.00	1.26
Chemical products	1.65	1.50	1.26
Mineral products	1.45	3.00	1.26
Metals	1.78	3.00	1.26
Metal products	1.87	3.00	1.26
Transport equipment	1.77	3.00	1.26
Electronic equipment	2.20	0.50	1.26
Machinery equipment	1.95	0.50	1.26
Electricity	1.40	0.50	1.26
Gas manufacture	1.40	0.50	1.26
Water	1.40	0.50	1.26
Construction	0.95	3.00	1.26
Trade	0.95	3.00	1.40
Transports	0.95	3.00	1.68
Private services	0.95	0.75	1.26
Government services	0.95	1.50	1.26

Source: Armington elasticities and elasticities of substitution among primary factors are from Version 7 of the GTAP database; CET elasticities are assumed

Annex A3: Change in Energy Intensities

Table A3 Change in energy intensities (%)

	CT_HS	CT_LT
Agriculture	-4.91	-5.27
Coal	-0.34	-0.47
Crude oil	0.66	0.52
Natural gas	0.03	-0.09
Minerals	-6.61	-6.92
Food products	-4.79	-5.83
Textiles	-4.93	-6.62
Wood products	-3.56	-4.29
Paper products	-5.45	-6.52
Petroleum products	0.07	0.04
Chemical products	-4.36	-5.15
Mineral products	-5.93	-7.29
Metals	-4.73	-5.51
Metal products	-6.25	-7.96
Transport equipment	-2.94	-4.87
Electronic equipment	-5.29	-6.47
Machinery equipment	-5.52	-7.43
Electricity	-4.14	-4.60
Gas manufacture	-4.64	-6.52
Water	-5.96	-7.86
Construction	-4.65	-6.24
Trade	-6.47	-7.22
Transports	-7.26	-8.76
Private services	-6.30	-7.81
Government services	-5.56	-8.30

Source: model simulation results

Annex A4: Change in Exports and Imports

Table A4 Change in exports and imports (%)

Industries	CT_HS		CT_LT	
	Exports	Imports	Exports	Imports
Agriculture	0.28	-1.84	3.13	-0.78
Coal	-5.04	-25.53	-4.90	-26.45
Crude oil	5.52	-16.90	5.61	-17.33
Natural gas	14.63	-36.37	14.32	-35.84
Minerals	2.63	-5.99	3.35	-5.54
Food products	0.41	-2.19	2.62	-0.70
Textiles	0.74	-1.67	4.10	-0.19
Wood products	-19.95	3.57	-19.11	4.92
Paper products	3.49	-3.46	5.61	-2.42
Petroleum products	3.80	-15.03	3.46	-15.13
Chemical products	-16.38	2.05	-16.14	3.40
Mineral products	-4.29	-0.20	-3.16	-0.05
Metals	-8.57	-0.66	-8.52	0.30
Metal products	-3.80	-1.27	-1.26	-0.88
Transport equipment	2.68	-1.45	5.63	-0.57
Electronic equipment	-2.73	-0.29	-1.60	0.41
Machinery equipment	-0.68	-1.31	0.83	-1.45
Electricity	-9.16	5.00	-8.99	6.58
Gas manufacture	-8.28	-10.55	-7.09	-10.91
Water	-0.87	-1.55	0.63	-1.43
Construction	4.63	-1.81	5.87	-1.95
Trade	8.62	-4.02	9.45	-2.61
Transports	-7.03	-0.43	-5.84	0.64
Private services	0.66	-2.96	2.14	-2.24
Government services	1.89	-1.28	4.18	-2.18

Source: model simulation results

Annex A5: Change in Activity Prices of Different Aggregates

Table A5 Change in activity prices of different aggregates (change in %)

	CT_HS						CT_LT					
	ACT	PVAE	PINT	PVLL	PVKE	PVE	ACT	PVAE	PINT	PVLL	PVKE	PVE
Agriculture	-0.21	-0.19	-0.25	-1.06	2.62	12.07	-0.65	-0.78	-0.45	-2.13	3.57	13.37
Coal	-6.41	-12.42	0.52	-18.60	5.12	8.71	-6.68	-12.90	0.52	-19.54	5.96	9.60
Crude oil	-1.29	-1.92	0.05	-0.23	-3.59	7.20	-1.23	-1.84	0.06	-0.78	-2.88	8.01
Natural gas	-4.01	-6.35	-2.03	-11.05	-0.56	7.77	-3.82	-6.15	-1.85	-11.33	0.23	8.76
Minerals	-2.54	-4.02	-0.67	-3.59	-4.39	11.49	-2.51	-3.98	-0.65	-4.32	-3.69	12.74
Food products	-0.62	-1.16	-0.42	-1.37	-1.07	9.51	-0.79	-1.30	-0.60	-3.38	-0.30	10.49
Textiles	-0.12	-0.48	0.06	-1.37	0.75	8.48	-0.44	-1.34	0.01	-3.38	1.51	9.34
Wood products	3.94	6.24	0.27	-1.38	8.08	8.87	4.08	6.55	0.17	-3.37	8.99	9.79
Paper products	-1.20	-3.17	-0.28	-1.36	-3.97	11.92	-1.32	-3.30	-0.39	-3.39	-3.27	12.86
Petroleum products	-3.31	-3.39	-0.74	-1.37	-3.42	-3.21	-3.17	-3.25	-0.74	-3.38	-3.24	-3.14
Chemical products	4.16	6.25	1.49	-1.35	8.09	10.94	4.47	6.69	1.64	-3.40	9.18	12.12
Mineral products	1.36	2.55	0.12	-1.37	5.28	10.06	1.24	2.25	0.19	-3.38	6.23	11.15
Metals	1.33	2.42	0.35	-1.37	3.40	10.03	1.53	2.69	0.49	-3.38	4.28	11.07
Metal products	0.90	0.92	0.89	-1.37	3.98	9.71	0.63	0.10	0.99	-3.38	4.85	10.71
Transport equipment	-0.18	-2.25	0.23	-1.36	-4.33	9.49	-0.38	-3.46	0.24	-3.39	-3.64	10.39
Electronic equipment	1.22	2.26	0.67	-1.35	4.23	9.62	1.18	2.06	0.72	-3.40	5.11	10.61
Machinery equipment	0.24	-0.18	0.59	-1.36	2.00	8.67	-0.23	-1.25	0.62	-3.39	2.79	9.56
Electricity	8.35	diff.	-1.09	diff.	diff.	diff.	9.20	diff.	-1.03	diff.	diff.	diff.
Gas manufacture	-0.59	-0.74	-0.34	-1.33	0.14	7.86	-1.19	-1.72	-0.31	-3.42	0.88	8.68
Water	0.10	0.39	-0.51	-1.33	2.83	9.12	-0.52	-0.53	-0.49	-3.42	3.66	10.06
Construction	-1.11	-2.73	0.62	-1.37	-3.72	10.79	-1.33	-3.16	0.63	-3.38	-3.00	11.92
Trade	-2.61	-3.86	0.43	-1.37	-4.17	12.18	-2.34	-3.46	0.38	-3.38	-3.47	13.47
Transports	1.95	3.22	-0.49	-1.36	5.19	13.80	2.01	3.33	-0.52	-3.39	6.30	15.29
Private services	-1.54	-2.04	-0.55	-1.29	-2.49	12.94	-1.82	-2.39	-0.68	-3.46	-1.72	14.33
Government services	-0.82	-1.18	-0.11	-1.26	-0.87	10.67	-1.97	-2.85	-0.24	-3.50	-0.09	11.73

Source: model simulation results