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Prof. Dr. Harald Grethe

# Carbon Taxation in Russia: Prospects for a Double Dividend and Improved Energy Efficiency

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Anton Orlov
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Leiter des Kolloquium: Prof. Dr. Markus Rodehutscord

Berichterstatter, 1. Prüfer: Prof. Dr. Harald Grethe

Mitberichterstatterin 2. Prüferin: Prof. Dr. Martina Brockmeier

3. Prüfer: Prof. Dr. Tilman Becker

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# Publications Based on the Thesis

Parts of this thesis are based on work which has been accepted for publication in peer-reviewed international journals:

1) Orlov, A., Grethe, H., 2012. Carbon taxation and market structure: a CGE analysis for Russia. *Energy Policy* 51, 696-707.

2) Orlov, A., Grethe, H., McDonald, S., 2013. Carbon taxation in Russia: prospects for a double dividend and improved energy efficiency. *Energy Economics* 37, 128-140.

The first manuscript, which forms the basis of Sections 3.2.2 and 7.5, has been published in *Energy Policy*. The second manuscript, which provides the basis of Sections 3.2.1, 7.3 and 7.4, has been published in *Energy Economics*.

Anton Orlov is the lead author of both articles. He developed the concepts, drafted all text parts and carried out model developments and simulations. Model developments and results were intensively discussed with the co-authors. Furthermore, co-authors significantly contributed to embedding the analysis in a political context and refining the manuscripts.

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# Abbreviations

| | |
|---|---|
| APEC | Asia Pacific Economic Cooperation |
| CDR | Cost disadvantage ratio |
| CES | Constant elasticity of substitution |
| CET | Constant elasticity of transformation |
| CGE | Computable general equilibrium |
| CHP | Combines heat and supply |
| CIS | Commonwealth of Independent States |
| CRTS | Constant return to scale |
| CT_HS | Introduction of carbon taxes compensated by an increase in lump-sum transfers |
| CT_LT | Introduction of carbon taxes compensated by a reduction in taxes on labour income |
| EFA | Energy Forecasting Agency |
| EIA | Energy Information Administration |
| EV | Equivalent variation |
| FAS | Federal Anti-Monopoly Service |
| FSSS | Federal State Statistics Service |
| FTS | Federal Tariff Service |
| GAMS | General Algebraic Modelling System |
| GDP | Gross domestic product |
| Gg | Giga gram |
| GHG | Greenhouse gas |
| GTAP | Global Trade Analysis Project |
| GW | Giga watt |
| IRTS | Increasing return to scale |
| JSC | Joint stock company |
| LES | Linear expenditure system |
| Mtoe | Million tons of oil equivalent |
| OECD | Organisation of Economics Co-operation and Development |
| Q.E.D | Quod erat demostrandum (Latin) |
| ROS | Rates of return on sales |
| ROW | Rest of the world |
| SAM | Social accounting matrix |

| | |
|---|---|
| TGC | Territorial generation companies |
| Ttoe | Thousand tons of oil equivalent |
| USD | United States Dollar |
| WGC | Generation companies of the wholesale electricity market |

# Summary

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 dioxide emissions – some 5% to 6% of global carbon dioxide emissions (EIA, 2011a). It has been estimated (World Bank, 2008) that Russia could reduce its use of primary energy use by 45% with consequent economic and environmental benefits. High energy and carbon intensity of the Russia economy is, *inter alia*, explained by low energy prices due to high export taxes as well as administrative regulation of domestic prices of gas and electricity and low environmental taxes.

Carbon taxes are one such Pigouvian tax and they would address concerns on several fronts simultaneously. In the short to medium term they would, *inter alia*, lead to lower GHG emissions and encourage the diffusion of more energy efficient technologies. In the longer term, the increased cost of energy inputs is expected to induce technological progress.

In this analysis, the macroeconomic and sectoral effects of carbon taxes on the Russia economy are examined. This analysis addresses the following objectives: i) to test the double dividend hypothesis under perfect and imperfect competition in output markets, to analyse ii) the incidence of carbon taxes, iii) impacts on sectoral competitiveness, iv) effects on income equity, and v) interactions of carbon taxes with other taxes. A computable single-country multi-sector comparative static CGE model is employed. To increase the credibility of the quantitative results, the standard version of the model has been modified by i) incorporating energy substitution by industries and the household sector, ii) disaggregating the electricity sector into four power generation technologies, iii) incorporating a Cournot oligopoly in some output markets, iv) incorporating a labour supply function, and v) modelling Russia as a large country with respect to the natural gas market.

Three experiments are run: i) an introduction of carbon taxes compensated by an increase in lump-sum transfers, ii) an introduction of carbon taxes compensated by a reduction in taxes on labour income under perfect competition, and iii) an introduction of carbon taxes compensated by a reduction in taxes on labour income under a Cournot oligopoly in some output markets. The magnitude of carbon taxation aims at a targeted reduction of carbon dioxide emissions by 10% through a proportional increase in carbon tax rates. Carbon taxes are levied on crude oil, coal, petroleum products, natural gas, and gas manufacture. The experiments are accompanied by sensitivity analyses to ensure the robustness of the results.

Simulation results show that introducing carbon taxes compensated by an increase in lump-sum transfers leads to welfare losses. The economy is adversely affected by carbon taxes via increased energy costs so that there are reductions in domestic consumption as well as production in almost all sectors. In contrast, substituting carbon taxes for labour taxes can lead to welfare gains. Other macroeconomic and sectoral effects resulting from substituting carbon taxes for labour taxes are summarized as follows:

1) There are increases in the supply of unskilled and skilled labour. This indicates the occurrence of an employment double dividend. High labour supply leads to reductions in net wages, implying lower labour costs for industries. Moreover, supply of land is increased associated with higher production of agricultural products.

2) Returns to capital and natural resources are reduced because of lower demand for these factors so that the burden of carbon taxes is not fully passed on to final consumers, yet is partially absorbed by lower factor prices. This indicates the tax-shifting effect between labour, capital and natural resources.

3) Substituting carbon taxes for labour taxes results in higher revenues from export taxes because of both a depreciation of the currency and higher export supplies of energy commodities as well as non-energy intensive commodities. In particular, the increase in revenues from export taxes on crude oil, natural gas, and petroleum products is strongly pronounced. Export taxes lower the domestic price level of energy so that there is oversupply of energy in the domestic market. Therefore, introducing carbon taxes has also a corrective effect since this leads to an increase in export supply and a reduction in domestic demand for energy. Increases in export supply of energy are associated with higher revenues from export taxes, which reduce the cost of the environmental tax reform. Moreover, there is an increase in the revenue from land taxes. Intuitively, high revenues from other taxes allow a larger reduction in labour taxes, furthermore alleviating the tax distortion in the labour market.

4) In contrast, substituting carbon taxes for labour taxes leads to reductions in the revenues from labour taxes because of both lower tax rates and wages. Revenues from capital taxes and mineral resource extraction taxes are also reduced due to lower returns to these factors. Furthermore, revenues from consumption taxes decrease due to a lower value of total consumption.

5) Total domestic production of energy commodities is reduced, driven by lower domestic demand. Nevertheless, domestic producers of energy become more competitive in domestic and export markets because of lower production costs and a depreciation of the currency. As a result, there are increases in the export supply of crude oil, coal, petroleum products, and natural gas.

6) Energy intensive commodities such as electricity, wood products, chemical products, and metals are affected most adversely by the introduction of carbon taxes. Due to high energy costs, domestic producers of energy intensive commodities become less competitive compared to foreign firms. As a result, there are increases in import demand for some energy intensive commodities, whereas export and domestic demand for all domestically produced energy intensive commodities is reduced.

7) In contrast, domestic producers of non-energy intensive commodities such as textiles, agriculture, and food products become more competitive in domestic and export markets compared to foreign rivals. As a result, substituting carbon taxes for labour taxes leads to increases in export supplies of all non-energy intensive commodities. Moreover, domestic demand for most domestically produced non-energy intensive commodities is also increased because of increased household income, while import demand for non-energy intensive commodities is reduced via a substitution effect.

8) Carbon taxes have a strong regressive impact on income distribution since the expenditure shares on coal, gas and electricity are especially high by poor households compared to those by rich households, while the expenditure share on petroleum products is larger by rich households. Despite a regressive impact of carbon taxes, the environmental tax reform tends to be quite progressive, if revenues from carbon taxes are refunded through a reduction in labour taxes or as lump-sum transfers in favour of poor household groups. Hence, substituting carbon taxes for labour taxes cannot only improve the national welfare, but also this can reduce income inequality in Russia.

To examine the stability of the results under different model parameterization, several sensitivity analyses were carried out. The sensitivity analyses indicate that the macroeconomic and sectoral effects of carbon taxes strongly depend on i) the labour supply elasticity, ii) elasticities of substitution between labour and the capital-energy aggregate, iii) elasticities of substitution between capital and energy, and iv) international capital mobility. For instance, substituting carbon taxes for labour taxes results in higher welfare gains under a high labour supply elasticity as well as high elasticities of substitution between labour and the capital-energy aggregate and low elasticities of substitution between capital and energy. Intuitively, the more elastic demand and supply of labour, the larger welfare losses arising from labour taxation. Therefore, substituting carbon taxes for labour taxes tends to be a more preferable revenue recycling strategy under elastic demand and supply of labour. Another crucial aspect is the tax-shifting effect between labour and capital. Under the assumption of international capital immobility, capital bears some burden of carbon taxation. The higher elasticities of substitution between labour and the capital-energy aggregate as well as the lower elasticities of substitution between capital and energy, the more pronounced the tax-shifting effect. The magnitude of the tax-shifting effect between capital and labour is indicated by reductions in the return to capital. In contrast, given the assumption of perfect capital mobility across borders, introducing carbon taxes under both revenue recycling schemes – an increase in lump-sum transfers to households and a reduction in tax rates on labour income – leads to substantial welfare losses compared to those in the central case simulation.

In the central policy simulation, substituting carbon taxes for labour taxes improves the national welfare. Nevertheless, non-tax distortions such as imperfect competition should not be neglected. In the presence of a Cournot oligopoly in the market for natural gas, petroleum products, chemical products, metals, and minerals, the cost of carbon taxation in terms of welfare is higher compared to perfect competition being assumed. The reason for this is that carbon taxes exacerbate pre-existing distortions arising from imperfect competition as well as induce losses in economies of scale. As a result, substituting carbon taxes for labour taxes

## Zusammenfassung

Russland verfügt nicht nur über einen der größten Vorräte an kohlenstoffbasierter Energie wie Kohle, Rohöl und Gas, sondern ist auch einer der größten Energieverbraucher. Darüber hinaus ist Russland für einen überproportional großen Anteil von Kohlendioxid-Emission - etwa 5% bis 6% – der weltweiten Kohlendioxidemission verantwortlich.

Mit der Einführung einer Kohlendioxidsteuer könnten gleichzeitig unterschiedliche Wirkungen erzielt werden. Kurz- und mittelfristig würden Kohlenstoffsteuern sowohl zu einer Reduzierung von Treibhausgasemissionen als auch zur Einführung von energieeffizienteren Technologien führen. Langfristig wird erwartet, dass hohe Energiekosten den Anreiz zur Entwicklung und zur Investition in energiesparenden technischen Fortschritt erhöhen.

Die vorliegende Arbeit analysiert und bewertet die makroökonomischen und sektoralen Auswirkungen einer Einführung von Kohlenstoffsteuern auf die russische Wirtschaft. Die Ziele der Arbeit bestehen darin, die Hypothese der doppelten Dividende für den Fall des vollkommenen und des unvollkommenen Wettbewerbs auf Gütermärkten zu überprüfen und die Inzidenz einer Kohlenstoffsteuer, ihre Auswirkungen auf die sektorale Wettbewerbsfähigkeit, ihre Auswirkungen auf die Einkommensverteilung und die Interaktion von Kohlenstoffsteuern mit anderen Steuern zu analysieren und zu bewerten.

Als methodischer Ansatz wurde ein Single-Country und Multi-Sektor Model gewählt. Dabei handelt es sich um ein komparativ statisches Model. Zur Verbesserung der Glaubwürdigkeit der Simulationsergebnissen wurde die Standardversion des Modells modifiziert, indem die Substituierbarkeit des Energieverbrauches bei Industrien und Hausehalten eingeführt, der Stromsektor in vier Subsektoren untergliedert, ein Cournot-Oligopol in Gütermärkten eingebaut, eine Arbeitsangebotsfunktion eingeführt und Russland als ein großes Land in Bezug auf den Markt für Gas dargestellt wurde.

Drei Experimente werden durchgeführt:

1) Die Einführung einer Kohlenstoffsteuer, deren Steuererträge durch eine Erhöhung von Pauschalbeträgen zurückerstattet werden.
2) Die Einführung einer Kohlenstoffsteuer, deren Steuererträge über die Senkung von Steuern auf das Arbeitseinkommen bei vollkommenem Wettbewerb auf Gütermärkten kompensiert werden.
3) Die Einführung einer Kohlenstoffsteuer, deren Steuererträge durch eine Senkung von Steuern auf das Arbeitskommen für den Fall des Vorliegens eines Cournot-Oligopols auf Gütermärkten zurückerstattet werden.

Durch die Einführung der Kohlenstoffsteuer wird eine Reduzierung von Kohlendioxidemissionen um 10% erreicht. Die Steuern fallen beim Verbrauch von Rohöl, Kohle, Erdölprodukte, Erdgas und Industriegas an. Die Experimente werden von Sensitivitätsanalysen begleitet, um die Robustheit der Ergebnisse zu gewährleisten.

Die Ergebnisse der durchgeführten Simulationen zeigen, dass die Einführung einer Kohlenstoffsteuer, deren Steuererträge durch eine Erhöhung von Pauschalbeträgen zurückerstattet werden, zu Wohlfahrtsverlusten führt. Im Gegensatz dazu ergeben sich

Wohlfahrtsgewinne, wenn ein teilweiser Ersatz der Arbeitseinkommensteuern durch Kohlenstoffsteuern erfolgt.

Bei der Analyse konnten weiterhin folgende makroökonomische und sektorale Effekte festgestellt werden:

1) Es erfolgt ein Anstieg des Arbeitsangebots, der auch als Beschäftigungsdoppeldividende bezeichnet wird. Die Beschäftigungserhöhung hat eine Senkung der Nettolöhne zur Folge. Damit sinken die Lohnkosten für die Industrien.

2) Die Renditen für das Kapital und die natürliche Ressourcen sinken aufgrund fallender Nachfrage nach diesen Produktionsfaktoren. Infolgedessen fällt die Last der Kohlenstoffbesteuerung nicht vollständig auf die Endverbraucher in Form von hohen Konsumentenpreisen, sondern wird teilweise durch niedrigere Faktorpreise gedämpft.

3) Die Einführung einer Kohlenstoffsteuer mit einer kompensierenden Senkung der Arbeitseinkommensteuern hat eine Erhöhung der Steuereinnahmen von Exportsteuern aufgrund einer Geldabwertung und steigenden Exporten von Energieprodukten und nicht energieintensiven Produkten zur Folge. Insbesondere, der Anstieg der Steuereinnahmen von Exportsteuern auf Rohöl, Erdgas und Erdölprodukte ist stark ausgeprägt. Hohe Steuereinnahmen gewährleisten eine weitere Senkung der Arbeitseinkommensteuern, dadurch werden die Wohlfahrtskosten der ökologischen Steuerreform reduziert.

4) Die Steuereinnahmen aus Arbeitseinkommen sinken als Folge einer Reduzierung der Steuersätzen und sinkender Nettolöhne. Die fallenden Renditen für Kapital und natürliche Ressourcen führen zur niedrigeren Einnahmen bei Kapitaleinkommensteuern und Steuern auf die Gewinnung von natürlichen Ressourcen. Außerdem sinken die Steuereinnahmen bei Verbrauchersteuern aufgrund des niedrigeren Gesamtverbrauchs.

5) Die Gesamtproduktion an Energieprodukten schrumpft infolge der sinkenden Nachfrage. Nichtsdestotrotz werden die inländischen Produzenten von Energieprodukten konkurrenzfähiger auf Binnen- und Auslandsmärkten. Gründe dafür sind eine Geldabwertung und fallende Produktionskosten. Infolgedessen steigen die Exporte von Rohöl, Erdölprodukten und Erdgas.

6) Energieintensive Industrien wie Stromerzeugung und chemische Industrie sind stark von hohen Energiekosten betroffen. Daher werden die inländischen Produzenten weniger konkurrenzfähig im Vergleich zu ausländische Firmen sein. In Folge dessen steigt die Nachfrage nach importierten energieintensiven Produkten, während Export- und Binnennachfrage nach inländisch produzierten energieintensiven Produkten sinkt.

7) In Gegensatz dazu gewinnen die inländischen Produzenten von nicht energieintensiven Produkten – wie zum Beispiel Nahrungsmittel, Textilprodukte und Agrarprodukte – an Wettbewerbsfähigkeit gegen die ausländischen Konkurrenten. Der Grund dafür sind sinkende Arbeits- und Kapitalkosten. Damit steigt durch die zu erwartenden Substitutionseffekte nicht nur das Exportangebot, sondern auch die Inlandsnachfrage nach vielen inländisch produzierten, nicht energieintensiven Produkten.

8) Die Kohlenstoffsteuer hat Auswirkungen auf die Einkommensverteilung in den Haushalten, da die Ausgabenanteile für Kohle, Gas und Elektroenergie in armen höher sind als in reichen Haushalten. Trotz eines regressiven Charakters der Kohlenstoffsteuer ist die ökologische Steuerreform im Falle einer kompensierenden Senkung der Arbeitseinkommensteuern progressiv. Deshalb kann ein teilweiser Ersatz der Arbeitseinkommensteuern durch Kohlenstoffsteuern nicht nur die Wohlfahrt erhöhen, sondern auch die Einkommensungleichheit reduzieren.

Verschiedene Sensitivitätsanalysen wurden durchgeführt, um die Robustheit der Ergebnisse nachzuweisen. Die Ergebnisse zeigen, dass makroökonomische und sektorale Effekte der Kohlstoffbesteuerung stark abhängig sind von der Elastizität des Arbeitskräfteangebots, den Substitutionselastizitäten zwischen Arbeit und dem Kapital-Energie-Aggregat, den Substitutionselastizitäten zwischen Kapital und Energie, und der internationalen Kapitalmobilität. Die Einführung einer Kohlenstoffsteuer mit kompensierender Senkung der Arbeitseinkommensteuern führt zu hohem Wohlfahrtsgewinn, wenn die Elastizität des Arbeitskräfteangebots sowie auch Substitutionselastizitäten zwischen Arbeit und dem Kapital-Energie-Aggregat hoch sind und Substitutionselastizitäten zwischen Kapital und Energie niedrig sind. Ein anderer wichtiger Aspekt ist die Steuerüberwälzung zwischen Kapital und Arbeit. Je höher Substitutionselastizitäten zwischen Arbeit und dem Kapital-Energie-Aggregat und je niedriger Substitutionselastizitäten zwischen Kapital und Energie sind, desto stärker ist der Steuerüberwälzungseffekt ausgeprägt.

Unter der Annahme eines Oligopols in den Märkten für Erdgas, Erdölprodukte, chemische Erzeugnisse, Metalle und Minerale sind die Wohlfahrtkosten der Kohlenstoffbesteuerung höher als im Falle des vollkommenen Wettbewerbs. Der Grund dafür ist, dass Kohlenstoffsteuern die sich durch einen unvollkommenen Wettbewerb ergebenden Verzerrungen verschärfen und zu Verlusten von Skaleneffekten führen.

# 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. For example, to produce one dollar of GDP, Russia requires by 28% more energy than Canada, a country with similar climatic conditions, and twice more than European countries on average (EIA, 2011a). It has been estimated (World Bank, 2008) that Russia could reduce its use of primary energy use by some 45%, with consequent economic and environmental benefits. Furthermore, Russia accounts for a disproportionately large share of global carbon dioxide emissions – some 5% to 6% of global carbon dioxide emissions (EIA, 2011a); even after making allowance for climatic conditions. The carbon intensity in Russia accounted for 1.816 metric tons of $CO_2$ per thousand USD in 2009, whereas the world average was 0.620 (EIA, 2011a). Approximately by 2035, Russia would have the highest level of carbon dioxide emissions per capita among non-OECD countries (EIA, 2011b). In large part, the high carbon dioxide 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, which has the greatest technical energy saving potential, but the residential building, manufacturing, and transport sectors also have substantial scope for improvement energy efficiency (Bashmakov, 2009).

Much attention has been given to the issue of energy efficiency in Russia. Improvement of energy efficiency is one of the most important aspects of the Russian energy policy (Ministry of Energy, 2009). However, energy using technologies are typically embedded in capital equipment, e.g., power stations, smelters, etc., and buildings which have long productive lives, and hence the pace of technological change is inevitably a costly and long process. It raises concern that there is underinvestment in energy efficiency in Russia, i.e., an energy efficiency gap exists between the current and the social optimal energy use (Kozuchowski, 2008). There are different reasons which can slow down technical modernization. The replacement of technologies in Russia is particularly slow due to a combination of non-market failures – underestimation of adoption costs, high discount rates, and heterogeneity of energy users – and market failures – lack of information, principle-agent problems, and low energy prices because of inefficient price regulation and non-internalized environmental externalities (World Bank, 2008). On grounds of economic efficiency, only the existence of market failure can provide justifications for government intervention (Jaffe and Stavins, 1994a, 1994b).

This analyses focuses on non-internalized negative externalities considered as one of the reasons for the high energy/carbon intensity in Russia. Environmental taxes are small in Russia: for example, environmental payments paid by thermal power generation companies account for less than 0.1% of their total production costs, being considerably lower compared to many developed countries (EFA, 2009a).

Carbon taxes are one such Pigouvian tax and in Russia they would, potentially, address concerns on several fronts simultaneously. In the short to medium term they would, *inter alia*, i) reduce $CO_2$ and other emissions stemming from the use of energy commodities, ii) induce energy users to optimize the energy efficiency of existing plants, iii) substitute lower emission energy sources for higher emission sources and iv) induce the adoption of 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; Popp, 2002).

Carbon taxation is not high on the political agenda in Russia. Nevertheless, recently there has been a political discourse in Russia regarding increases of environmental payments (Kozuchowski, 2008; MNRERF, 2011). Although Russia has signed the Kyoto protocol and is subject to limits on its total carbon dioxide emissions, Russia currently is substantially below its limit and there would be no urgent need for a reduction of actual $CO_2$ emissions (UNFCCC, 2010a). According to Article 17 of the Kyoto protocol, Russia may sell part of its rights to emit $CO_2$ to other countries as part of the international carbon trade (UNFCCC, 2006). This may constitute an additional benefit from increasing carbon taxes in Russia which is politically discussed (RT, 2010).

Furthermore, according to the environmental taxation literature, an introduction of environmental taxes is often related to the concept of a strong double dividend, where substituting environmental taxes for other distortionary taxes can improve not only the environment, but also can reduce efficiency costs of the tax system (Goulder, 1995). The occurrence of a strong double dividend is ambiguous and depends, *inter alia*, on the tax system, economic structure, household preferences, and revenue recycling strategies (Goulder, 2002).

In case of environmental taxes, the revenue recycling policy becomes an important aspect. Compared to other possible revenue-recycling strategies, a reduction in labour taxes via revenues from environmental taxes is often considered as desirable, especially for Western economies, since it also addresses unemployment concerns (Bovenberg and van der Ploeg, 1994). In addition, some European countries have already implemented such environmental tax reforms, where an introduction of various environmental taxes (carbon dioxide or sulphur dioxide) is compensated by reduction in personal income taxes or social security contributions (Bosquet, 2000). The motivation for such a policy would be valid for Russia, too, since the level of unemployment in Russia accounted for 7.5% of the total labour force in 2010 (FSSS, 2012a). Moreover, distortions from labour taxation may be substantial in Russia: both taxes on labour income and social security contributions accounted for 27% of total government revenues in 2010 (FSSS, 2012b). Furthermore, substituting carbon taxes for labour taxes explicitly addresses the issue of income inequality, which is of high relevance for Russia. For example, the Gini coefficient for Russia was 0.42 in 2009 (FSSS, 2011).

The theoretical literature on environmental taxation is mainly focused on pre-existing distortionary taxes in the labour and capital markets (Goulder et al., 1997; de Mooij and Bovenberg, 1998), whereas interactions with other taxes such as export and import taxes, valued added taxes, excise taxes, and mineral resource extraction taxes are often neglected. Introducing environmental taxes, however, can indirectly affect the efficiency of the tax system through changes in tax bases. As a result, carbon taxes can either alleviate or exacerbate pre-existing distortions. Moreover, taxes other than labour and capital taxes can be a large source of government revenues. For example, revenues from export and import taxes, especially export taxes on crude oil, petroleum products, and natural gas, account for approximately 21% of total government revenues in Russia (FSSS, 2012b; Roskazna, 2010).

Apart from tax distortions on factor and commodity markets, another important aspect which is often neglected in empirical studies is distortions arising from imperfect competition. In any real economy, many markets can be characterized as being imperfectly competitive. For example, many resource-based sectors require high investments in plants and equipment and therefore exhibit decreasing average costs (Devarajan and Rodrik, 1991). According to analytical work on this issue, market structure can significantly affect the outcome of environmental tax reform. Therefore, imperfect competition is considered in some output markets in this analysis.

This analysis addresses the following objectives: i) to test the double dividend hypothesis under perfect and imperfect competition in output markets, to analyse ii) the incidence of carbon taxes, iii) impacts on sectoral competitiveness, iv) effects on income equity, and v) interactions of carbon taxes with other taxes. Two revenue recycling schemes are considered.

First, carbon taxes are introduced, where revenues from carbon taxes returned to households in lump-sum form. This experiment is considered as a reference experiment. Second, carbon taxes are introduced, where revenues from carbon taxes are refunded through a reduction in taxes on labour income. The results under the second experiment are compared to those under the first one.

The analytical models used by Parry (2001) and Stern (1987) are employed to provide a theoretical background for environmental taxation under perfect and imperfect competition. Moreover, the analytical model developed by Parry (2001) is extended by incorporating export taxes on polluting goods since the Russian economy strongly depends on revenues from export taxes. The numerical analysis is based on a computable comparative static single-country multi-sector general equilibrium model – an energy/environment adaptation of the STAGE model (McDonald, 2007). For the purpose of this analysis purpose, the core model is extended by the following modifications:

1) Incorporating factor-fuel as well as inter-fuel substitution for non-energy producing sectors.

2) Incorporating a two level nested linear expenditure system for households, where the first level consists of 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.

4) Incorporating imperfect competition and internal economies of scale into markets for natural gas, metals, minerals, chemical products, and petroleum products.

5) Incorporating a labour supply function.

6) Modelling Russia as a large country with respect to the natural gas market.

7) Incorporating the account of $CO_2$ emissions into the model.

To our knowledge this is the first such study for Russia, addressing the issue of a double dividend under perfect and imperfect competition in output markets. Moreover, despite comprehensive analytical work on environmental taxation under imperfect competition, there are few studies which treat this issue in complex numerical CGE models, which are able to reflect real-world complexities (e.g. Böhringer et al., 2008).

The study is organized as follows. Following the introduction, Chapter 2 provides a brief overview of energy efficiency and greenhouse gas emissions in Russia. In Chapter 3, the theoretical concept of energy efficiency as well as the concept of environmental taxation in the presence of pre-existing distortions is discussed. Chapter 4 presents the Russian tax system, especially taxes applied on production, consumption and trade of energy. Chapter 5 gives an overview of Russian energy markets, providing the basis of the modifications of the numerical model design. Chapter 6 provides a description of the database as well as this gives a detailed description the core model and its modifications. The results of simulations are presented in Chapter 7. The final chapter provides the conclusions together with comments on how the analysis could be further developed.

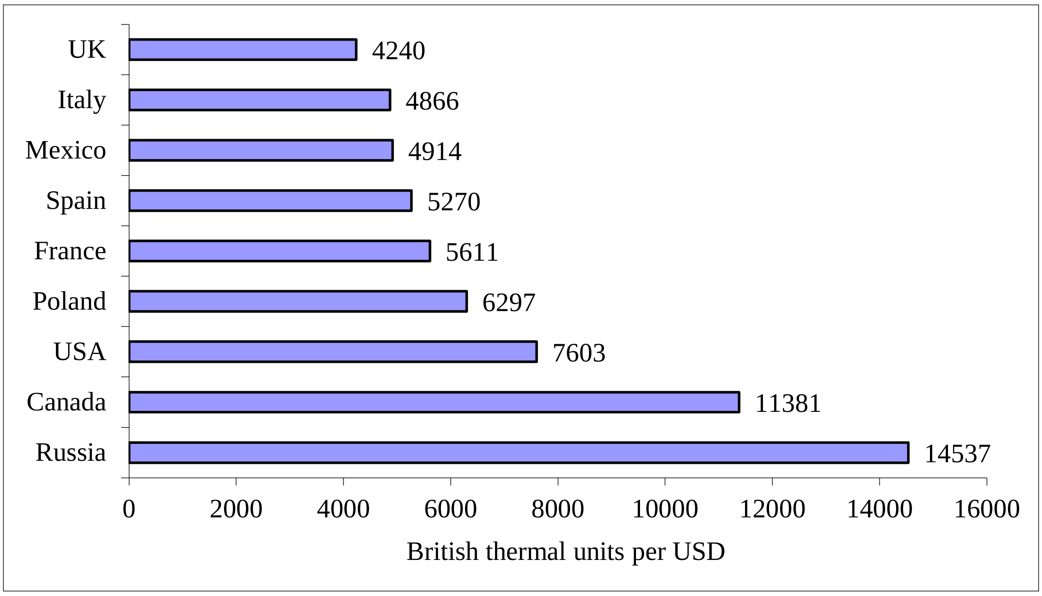
# 2 Energy Efficiency and GHG Emissions

Chapter 2 deals with energy efficiency of the Russia economy and GHG emissions. The chapter aims at raising the problem statement and is divided into three parts. The first part gives information about energy intensity of the Russian economy in comparison to other countries and provides the reasons for high energy intensity in Russia. The second part provides quantitative data on GHG emissions in Russia. This part defines the role of Russia with respect to global GHG emissions. The third part gives some estimation of energy saving potential in Russia and defines benefits, barriers and possible solutions to energy efficiency improvement.

## 2.1 Energy Intensity

Russia is highly energy intensive, more energy intensive compared to countries with similar GDP per capita. For example to produce one dollar of GDP, Russia requires by 28% more energy resources than Canada, a country with similar climatic conditions and economic structure, and twice more than European countries on average (Figure 2.1).

**Figure 2.1: Total Primary Energy Consumption per Dollar of GDP in 2008 (British thermal units per USD)**



Source: EIA (2011a).

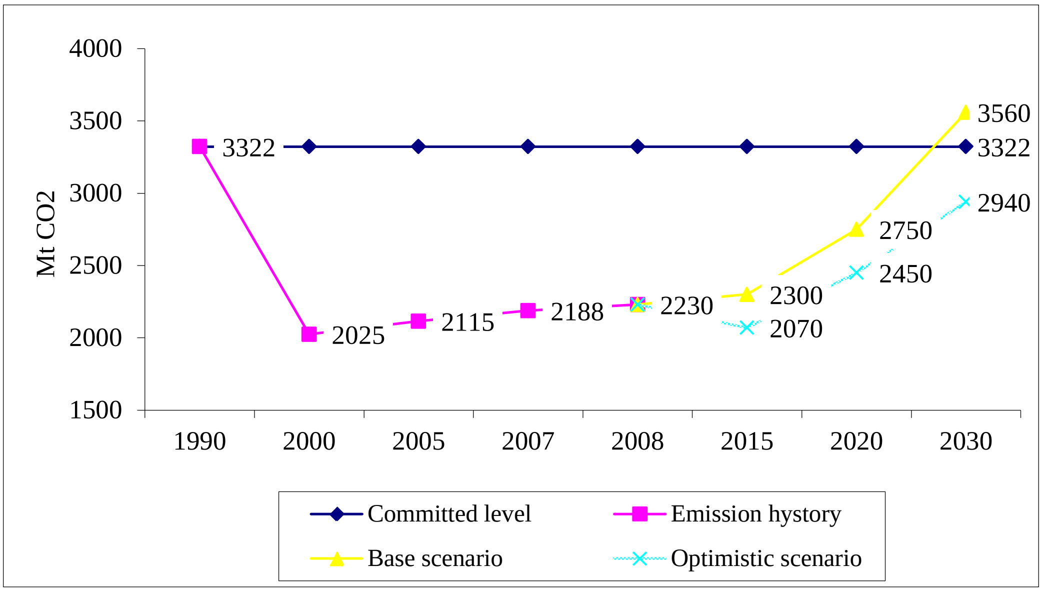
In general, the main reasons for high energy intensity in Russia are low domestic prices of energy, climatic conditions, economic structure and outdated equipment (Kulagin, 2008). From 1998 to 2008, the GDP energy intensity in Russia has been reduced by 42% because of structural change since the service sector has grown faster than industries (Bashmakov, 2011; Bashmakov and Mishack, 2012). Apart from structural change in favour of non-energy intensive sectors, a large scale technical modernization of the whole economy covers a large potential for further reductions in energy intensity in Russia.

## 2.2 Greenhouse Gas Emissions

Greenhouse gases (GHG) include direct greenhouse gases such as $CO_2$ (carbon dioxide), $CH_4$ (methane), $N_2O$ (nitrous oxide), PFCs (perfluorocarbons), HFCs (hydro fluorocarbons), and $SF_6$ (sulphur hexafluoride) (UNFCCC, 2012). GHG can be conditionally divided into energy and non-energy related emissions. Energy related emission – mainly $CO_2$ – come from industries and the power generation sector, whereas non-energy related – mainly $CH_4$ and $N_2O$ – emissions stem from the agricultural sector, waste, and land use (Stern, 2007).

High domestic demand for energy resources as well as low energy efficiency results in high GHG emissions. Russia is one of the largest contributors to carbon dioxide emissions in the world: for example, Russia was responsible for 5-7% of global $CO_2$ emissions in the period from 2000 to 2008 (EIA, 2011a). The carbon intensity of the Russian economy measured as metric tons of $CO_2$ per thousand USD was 1.82 in 2009, whereas the world's average was 0.62 (EIA, 2011a). Among other countries, Russia ratified the Kyoto protocol, which came into force on February 16th, 2005 (Federal Law No.128-FZ from October 27th, 2004). According to the Kyoto protocol, Russia may not exceed the level of GHG emissions recorded in 1990, which was approximately 3,322 Mt $CO_2e$ (metric ton of carbon dioxide equivalent). GHG emissions in Russia were 2,230 Mt $CO_2e$ in 2008, which is approximately 67% of the committed level. In other words, Russia has emission quotas on its commitments (Figure 2.2).

**Figure 2.2: Total Greenhouse Gas Emissions Excluding Emissions/Removals from Land Use, Land-Use Change and Forestry (Mt $CO_2$)**



Source: UNFCCC (2010a; 2010b).

The Russian growing economy will unambiguously require more energy resources. Therefore, domestic consumption of energy is expected to increase, which will lead to higher GHG emissions. Approximately by 2035, Russia would have the highest level of carbon dioxide emissions per capita among non-OECD countries so that environmental obligations could slow down the economic growth in the future (EIA, 2011b).

According to the Fifth National Report of the Russian Federation (UNFCCC, 2010a), the power generation sector is the largest source of GHG emissions, where the majority of GHG comes from $CO_2$ and $CH_4$. For example, $CO_2$ accounts for 79% of total GHG stemming from the power generation sector (Table 2.1). Other large sources of GHG are industries, agriculture and waste. GHG from industries consists mainly of $CO_2$ and F-gases. The largest contributors to GHG among industries are the metals (53.4%), mineral products (26.5%), and the chemical products sectors (11.7%). The agricultural sector is a large contributor to $CH_4$ and $N_2O$, whereas waste induces mainly $CH_4$.

**Table 2.1: GHG Emissions by Sources in 2007 (per cent)**

|  | Shares of GHG by sector | Shares in total sectoral GHG |  |  |  |  |
|---|---|---|---|---|---|---|
|  |  | $CO_2$ | $CH_4$ | $N_2O$ | F-gases | Total |
| Energy generation | 81.5 | 79.0 | 20.8 | 0.2 | 0.0 | 100 |
| Industries | 9.4 | 81.3 | 0.4 | 1.9 | 16.4 | 100 |
| Agriculture | 6.1 | 0.0 | 31.1 | 68.9 | 0.0 | 100 |
| Waste | 3.0 | 0.0 | 93.8 | 6.2 | 0.0 | 100 |
| **Total** | 100 | n.a. | n.a. | n.a. | n.a. | n.a. |

Source: UNFCCC (2010a).

Furthermore, according to the Fifth National Report of the Russian Federation (UNFCCC, 2010a), $CO_2$ accounts for 72% of the total GHG emission, followed by $CH_4$ (21.7%), $N_2O$ (4.7%), and F-gases (1.6%). Improvement of energy efficiency, especially in the power generation sector, can lead to a substantial reduction of GHG emissions (Bashmakov, 2009).

## 2.3 Energy Saving Potential

Most equipment applied in Russia is outdated and highly energy intensive. For example, the average operating time of all power generation plants in Russia is approximately 30 years. The majority of existing capacity in most industries was built during the Soviet Union era (EFA, 2009a). Large scale modernization of the whole Russian economy provides a large "source" of energy. Bashmakov (2009) distinguishes between three categories of energy saving potential:

1) **Technical energy saving potential.** "A technical energy saving potential is estimated as an amount of energy that can be saved by replacing the whole equipment stock with the best available one."

2) **Economic energy saving potential.** "An economic energy saving potential is defined as a part of technical energy saving potential which can be cost-effectively realized using public cost effectiveness criteria, such as discount rates, export prices of energy resources, positive and negative externalities."

3) **Market energy saving potential.** "A market energy saving potential is a part of economic energy saving potential which can be costs-effectively realized using private cost effective criteria, such as energy prices, capital costs, and risks. The economic energy saving potential is higher than the market energy saving potential since positive and negative external effects are often not accounted for in evaluating investment projects by private sectors."

Furthermore, according to Bashmakov (2009), the technical energy saving potential includes a direct and indirect potential for energy saving. The direct energy saving potential defines the amount of primary energy that can be saved by final consumers via technological (technical) modernization. The indirect energy saving potential accounts for energy that can be saved to produce and distribute a unit of a certain energy input. For example, a certain amount of gas or coal is required to produce 1 ton of oil equivalent (toe) of electricity, whereas production of gas and coal also requires electricity. The indirect energy saving potential is estimated through the whole energy supply chain. According to the study carried out by Bashmakov (2009), Russia could save about 45% of its total primary energy consumption in 2005, when both the direct and indirect effects are accounted for. Such improvement of energy efficiency will result in a substantial reduction of $CO_2$ emissions – approximately 50% of Russian total $CO_2$ emissions in 2005. Table 2.2 shows the estimated technical energy saving potential in Russia for 2005. The potential to reduce the total final energy consumption via technical modernization is estimated at 154 mtoe (million ton of oil equivalent) or 36% of the final energy consumption in 2005.

**Table 2.2: Technical Energy Saving Potential**

| | **Technical energy savings potential (Mtoe)** | **Technical energy savings potential (per cent to total)** |
|---|---|---|
| **Total,** including elimination of natural gas flaring | **294** | **100** |
| Elimination of natural gas flaring | 12 | 4.1 |
| **Total primary energy supply:** | **282** | **95.9** |
| Electricity generation (direct) | 22 | 7.5 |
| Electricity generation (indirect) | 40 | 13.6 |
| Heat supply (direct) | 9 | 3.1 |
| Heat supply (indirect) | 16 | 5.4 |
| Fuel production, transformation, transmission, and distribution (direct) | 17 | 5.8 |
| Fuel production, transformation, transmission, and distribution (indirect) | 24 | 8.2 |
| **Total final energy consumption:** | **154** | **52.4** |
| Agriculture and forestry | 3 | 1.0 |
| Mining | 1 | 0.3 |
| Manufacturing | 42 | 14.3 |
| Construction | 1 | 0.3 |
| Transport | 38 | 12.9 |
| Municipal utilities | 1 | 0.3 |
| Services | 15 | 5.1 |
| Residential | 53 | 18.0 |

Source: Bashmakov (2009).

Among non-energy producing sectors, the largest sources of energy efficiency improvement are the residential buildings, manufacturing, the transport sector, and services. The energy efficiency potential increases from 154 to 282 mtoe, if both the technical energy efficiency potential in the energy sector and indirect effects are accounted for. In particular, the power generation sector (electricity and heat) in Russia has a large energy saving potential. As shown in Table 2.2, technical modernization of the electricity generation sector (direct effect) can induce a reduction in energy consumption by 22 mtoe, whereas the indirect effect accounts for 40 mtoe. For heat supply, the direct effect is responsible for a reduction of energy consumption by 9 mtoe and the indirect effect yields 16 mtoe, whereas for fuel production and transportation it is 17 mtoe and 24 mtoe, respectively.

Based on Bashmakov (2009), some specific aspects of energy saving potential with respect to a certain sector are introduced below.

**Buildings.** Residential buildings are one of the largest energy users in Russia with the greatest potential for energy efficiency improvement: 53 mtoe. Total energy consumption of residential buildings is used for heating (58%), hot water (25%), cooking (10%), lighting (2.5%), and appliances (4.5%).

**Manufacturing.** The manufacturing sector is a large final consumer of energy, which has the second large technical energy savings potential (42 mtoe). In particular, ferrous metallurgy, pulp, and paper production have a great potential for energy efficiency improvement.

**Transportation.** The transport sector has the third largest technical energy saving potential among final users of energy: 38 mtoe or 41% of its energy consumption in 2005. The economic energy saving potential is evaluated at 95% of the technical energy saving potential, whereas the market energy saving potential accounts for 83%. About 49.3% of the technical energy saving potential falls into roads and 39.8% into gas pipelines, followed by aviation (4.3%), rail (2.7%), oil pipelines (1.6%), others (1.6%), and water transportation (0.7%).

**Agriculture.** Approximately 50% of total energy consumed by the agricultural sector is liquid fuels. Most tractors and other agricultural machineries used in Russia are outdated and very energy intensive. For example, consumption of diesel fuel per hectare as well as consumption of heat and electricity can be reduced by 50% in the agricultural sector via technical modernization.

**Electricity generation.** In particular, condensation power stations and combined heat and power (CHP) stations have a large technical energy saving potential. About 90% of technical energy saving potential is evaluated as economically viable, whereas 72% can be market viable with respect to fuel prices in 2010. The market energy saving potential is expected to be much higher, if opportunities of $CO_2$ credits trade are accounted for.

**Heat generation.** The economic energy saving potential in the heat generation sector is estimated at 90% of the technical energy saving potential, while the market potential varies from 30% to 87% depending on assumed fuel prices, operation costs, opportunities of $CO_2$ trading. The outdated heat supply system in Russia induces considerable losses of energy; for example, losses of municipal heat distribution are evaluated at 20-25% of energy consumption. The average losses of municipal and industrial heat distribution are estimated at 15%, whereas heat distribution losses in most West European countries are between 2% and 10% of energy consumption.

**Fuel production and transformation.** The technical potential to improve energy efficiency by oil extraction and petroleum refineries is estimated at 4.0-5.6 mtoe or 26%-37% of total energy consumed by the petroleum refinery. Another important source for energy efficiency improvement is technical modernization of the natural gas sector as well as utilization of associated natural gas. Consumption of energy in the gas sector can be reduced by 20% of energy consumed by the gas sector in 2005. The use of energy in the coal sector can be reduced by 0.26 mtoe or 15% of energy used by the coal sector in 2005.

**Benefits of energy efficiency improvement.** Improvement of energy efficiency in Russia would result in several economic and environmental benefits, which are summarized as follows (World Bank, 2008):

1) **Energy security.** According to the estimation carried out by IEA (2006), the main reserves of crude oil and natural gas in Russia are in decline. This raises concerns about the ability of Russian gas producers to satisfy growing domestic and export demand for energy resources. Realizing energy saving potential in Russia can unlock a large source of energy. Investment in energy efficiency in Russia can be more cost effective compared to investment in new production capacity.

2) **Economic development.** Higher energy costs will lead to decreases in profit. Investment in less energy intensive technologies, however, will support the competitiveness of domestic producers in domestic and export markets. Moreover,

decreasing energy intensity results in more revenues from export of energy via higher export supply. In addition, government expenditures on energy services are high in Russia and improvement of energy efficiency will reduce these expenditures.

3) **Environmental improvement.** Energy use, especially fossil fuel, induces high health risks for the population. Air pollution is one of the reasons for many diseases so that less energy consumption implies ultimately less pollution. Another important challenge related to energy use is climate change. Improvement of energy efficiency in Russia will lead to a decline of GHG emissions. As mentioned, the technical energy efficiency potential in Russia is associated with a reduction of carbon dioxide emissions by 50% of total $CO_2$ estimated for 2005. In particular, heat and electricity generation, transportation and distribution losses, and the manufacturing sector has the greatest potential for a reduction of $CO_2$ emissions.

4) **Carbon credits.** Finally, the level of GHG emissions in Russia in 2008 accounted for approximate 67% of the committed level of emissions. Therefore, Russia has emission quotas, which can be sold in international carbon markets (Article 17 of the Kyoto Protocol). Furthermore, a large technical energy saving potential provides opportunities to benefit from Joint Implementation projects (Article 6 of the Kyoto Protocol).

**Barriers and solutions to energy efficiency.** There are different barriers for energy efficiency improvement, such as lack of information, lack of organization, lack of technologies, lack of motivation and lack of funding (Bashmakov, 2009). According to a case study for Russia which was carried out by World Bank (2008), barriers and suggested solutions for energy efficiency improvement are summarized in Table 2.3. For more detail, see World Bank (2008).

**Table 2.3: Barriers and Solutions to Energy Efficiency in Russia**

| **Barriers** | **Solutions** |
|---|---|
| **Residential housing** | |
| • Apartment owners or building managers have little information on EE;<br>• Developers and their contractors have no incentives to improve EE;<br>• Apartment owners have no incentive to invest in EE;<br>• Apartment owners have limited access to capital to make EE investments; | • Disseminate information on energy efficiency;<br>• Make existing energy efficiency standards mandatory for the construction and renovation of buildings and monitor energy efficiency of buildings in use;<br>• Require that energy efficiency improvements be made as a condition of government financial support for capital repairs;<br>• Provide incentives for more widespread metering;<br>• Develop standardized performance-based management contracts for HOAs and building management companies;<br>• Establish a capital repairs loan guarantee facility;<br>• Introduce energy efficiency standards and labelling for lighting and household appliance; |
| **Public organization** | |
| • Public organization cannot retain any energy;<br>• Public organizations cannot enter into financing agreements, multi-year contracts, or contracts that pay for the investment through future savings;<br>• Procurement rules favour lowest cost of bid, not the lowest lifetime cost;<br>• Very little statistic information or awareness exists; | • Allow more budget flexibility;<br>• Change procurement legislation to allow for multi-year contracts;<br>• Prioritize EE equipment procurement;<br>• Set energy consumption targets based on benchmarking;<br>• Introduce autonomous status of public organizations;<br>• Disseminate information on energy efficiency; |
| **Industries** | |
| • A lack of awareness among managers;<br>• Macroeconomics constraints on banks;<br>• A failure of banks to understand energy efficiency investments;<br>• High transaction costs;<br>• Tariffs that lag producer prices;<br>• Inflexible electricity and gas supply contracts; | • Disseminate information on energy efficiency;<br>• Facilitate financing for EE investment through Russian financial institutions;<br>• Develop equipment standards and labels;<br>• Provide subsidies for transaction support;<br>• Provide fiscal incentives;<br>• Introduce taxation or cap-and trade schemes for pollutants and/or emission;<br>• Complete electricity and gas sector reforms; |
| **Heat supply sector** | |
| • Inappropriate tariff methodology;<br>• Political interference;<br>• Cost plus method;<br>• Tariff periods is too short;<br>• Legal structure and governance of municipal heat suppliers;<br>• Lack of information and sectoral coordination; | • Reform tariff methodologies;<br>• Price cap system;<br>• Full cost recovery;<br>• Transform municipal heat suppliers into commercial entities or PPP;<br>• Coordinate municipal heat supply development plants; |
| **Electricity sector** | |
| • Inappropriate tariff methodology;<br>• Bias toward new capacity;<br>• Exaggerated demand growth projection;<br>• Lack of coordination between energy service providers;<br>• Uncertainty over sector reforms; | • Reform tariff methodologies;<br>• Regulated assert base tariffs;<br>• Two part tariff;<br>• Remove cross-subsidies;<br>• Demand side management or rate payer funded energy efficiency programs;<br>• Clarify and standardize requirements and procedures for setting new plants and connecting to the grids; |

| | |
|---|---|
| **Gas flaring** | |
| • Remoteness of potential markets;<br>• Market structure that prevents third party access to spare pipeline capacity;<br>• Low price of dry natural gas and APG;<br>• Insufficient information on volumes of APG flaring and utilization;<br>• Soft penalties for excessive gas flaring; | • Improved monitoring and enforcement of utilization requirements, possibly through an independent regulatory body;<br>• Enact Federal legislation requiring APG utilization, including heavier fines and possible loss of operating licenses;<br>• Allow third-party access to Gazprom pipelines; |

Source: World Bank (2008).

One of the most important economic reasons for high energy intensity in Russia is low prices of energy. Domestic prices of energy are considerably lower compared to world market prices mainly because of administrative price regulation, high export taxes, and non-internalized negative environmental externalities.

## 2.4 Summary of the Chapter

The Russian economy is a highly energy- and carbon-intensive economy. The main reasons for this are outdated equipment, climatic condition and low domestic prices of energy. Nevertheless, Russia has a large potential for energy efficiency improvement with consequent economic and environmental benefits. It has been estimated (Bashmakov, 2009) that Russia could reduce its use of primary energy use by some 45% with a consequent reduction in GHG emissions. Energy efficiency can be improved through substitution effects (substitution between primary factors and energy) and through technological change (Gillingham et al., 2009). In the empirical analysis (Section 7), the only energy efficiency improvements resulting from factor-energy substitution are considered. Modelling technological changes will require a more elaborated dynamic framework.

# 3 Theoretical Background

Chapter 2 shows that there is a large technical potential for energy efficiency improvement in Russia. Realizing this potential covers economic and environmental benefits. In this context, it raises concerns whether there is underinvestment in energy efficiency and government intervention is required. Chapter 3 deals with the economic concept of energy efficiency and environmental regulation. The chapter is divided into two parts. The first part starts with the concept of an energy efficiency gap, followed by the discussion of possible policy instruments to improve energy efficiency. The second part is focused on environmental taxation as one of the powerful instruments to reduce emissions and to encourage investment in energy efficiency. This part aims mainly at addressing the theoretical aspects of an environmental tax reform with respect to economic efficiency and income equity, especially the concept of a double dividend is discussed in detail. Based on Chapter 2 that provides the problem statement and Chapter 3 that provides the theoretical background, the main objectives of this analysis are derived. Chapter 3 also aims at giving the basis for discussion of the empirical results as well as suggestions for further research.

## 3.1 Economics of Energy Efficiency

### 3.1.1 Energy Efficiency Gap

The Russian economy is very energy intensive, yet Russia has a large energy efficiency potential, which can be realized via technical modernization. It has been estimated (Bashmakov, 2009) that Russia could reduce its use of primary energy by some 45%. In the presence of such large technical energy efficiency potential, concerns are whether there is a gap between the current and the social optimal energy use in Russia. In other words, one can ask whether there is underinvestment in energy efficiency, which in turn can lead to overconsumption of energy.

In theory, there are three explanations for slow technology diffusion namely (1) non-market failures, (2) market failures, and (3) behavioural failures. The non-market failure explanation refers to incorrectness which can occur in the calculation of social optimal diffusion rates. These are classified as follows (Jaffe and Stavins, 1994a and 1994b; Jaffe et al., 2004):

1) **Overestimation of energy savings.** Energy savings are often overestimated.[1]

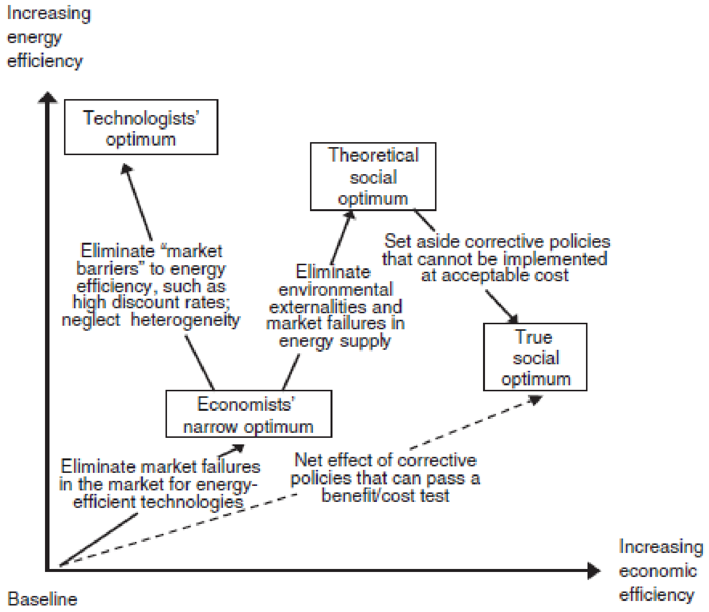
2) **Unaccounted adoption costs.** New technologies can have high adoption costs or other "hidden" costs, which often are not taken into consideration in cost-benefit analysis.

3) **High discount rates.** The irreversible nature of investment and uncertainty about future benefits and costs result in higher discount rates compared to those often used in the calculation of social optimal diffusion rates in various studies.

4) **Heterogeneity of energy users.** Some less energy intensive technologies can be economically efficient on average, but not for all individuals or firms because of heterogeneity.

High adoption costs and high discount rates can be considered as market barriers for faster technology diffusion. Since technical modernization is a long and costly process, the government can encourage this by using different command-control and market instruments. This will lead to higher energy efficiency, but not necessarily in higher economic efficiency, as illustrated in Figure 3.1. Energy efficiency measures energy use per unit of output, whereas economic efficiency measures overall economic costs per unit of output (Jaffe et al., 2004).

**Figure 3.1: Energy Efficiency Gap**



Source: Jaffe et al. (2004).

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[1] "Projects often are based on highly controlled studies that do not necessarily apply to actual realized savings in a particular situation (Jaffe et al., 2004)".

The second explanation for slow technology diffusion is market failures. From a theoretical point of view, the existence of market failures can justify government intervention for the reason of economic efficiency. The market failure explanations for slow technology diffusion are summarized as follows (Jaffe and Stavins, 1994a and 1994b; Jaffe et al., 2004):

1) **Lack of information.** Information is a public good, which can be underprovided because of a free rider problem. Moreover, the adoption of new technologies can provide positive externalities, since this gives information about experiences from using new technologies, i.e. the so-called learning by using effect.
2) **Principal-agent problem.** This problem can occur when builders or landlords decide about investment in energy efficiency, but energy costs are borne by purchasers. As a result, this can lead to an underinvestment in energy efficiency.
3) **Average-cost pricing**. Energy prices can differ from marginal social costs because of subsidies or average-cost pricing. Under average-cost pricing, marginal social costs to increase capacity can exceed the average-cost price. Therefore, investment in energy efficiency is not optimal since existing capacity can exceed the socially desirable level.
4) **Non-internalized negative environmental externalities.** Private firms do not have economic incentives to minimize external environmental costs. Therefore, marginal social damage from use of energy is not covered in energy prices. In particular, this becomes of high relevance, if concerns about climate change are taken into account.
5) **Non-internalized positive externalities.** There can be also positive externalities from introduction of less energy intensive technologies, i.e., learning by doing.

The third explanation for slow technology diffusion is behavioural failures. In addition to market failure, behavioural failures should also be corrected by government interventions. The three concepts from behavioural economics can be related to energy efficiency (Gillingham et al., 2009):

1) **Prospect theory: status quo effect.** Prospect theory is an alternative theory describing decision making behaviour to utility theory under uncertainties. This concept claims that consumers are irrationally reluctant to mover from the status quo. In the context of energy efficiency, as the status quo can be considered usage of conventional technologies.

2) **Bounded (limits) rationality.** This concept suggests that consumers are rational, yet there are limitations: (i) limited information with respect to possible alternatives, (ii) human mind has limited capacity to evaluate and process the information, and (iii) limited amount of time is available.

3) **Heuristic decision making.** Heuristics are simplifications of decisions process. There is evidence that consumers sometimes simplify their methods to evaluate energy savings benefits. This can lead to overconsumption of energy.

The issue of energy efficiency is very complex. There are different reasons for inefficient use of energy as well as there are different instruments to correct inefficiencies. The focus of this analysis lies on non-internalized environmental externalities as a market failure which, *inter alia*, cause slow technology diffusion and imply high pollution in Russia.

### 3.1.2 Environmental Policy and Technology Diffusion

There are different instruments that can accelerate the diffusion of new energy-efficient technologies, such as pollution taxes, adoption subsidies, tax credits, tradable permits, and command-control instruments. According to the theoretical literature, economic incentive-based instruments, such as adoption subsidies and pollution taxes, can be more efficient in providing incentives for technology adoption compared to command-control instruments (Kerr and Newell, 2004; Newell et al., 2006). Furthermore, according to the empirical studies carried out by Jaffe and Stavins (1995) and Hassett and Metcalf (1995), adoption subsidies can be more effective compared to taxes in encouraging technology diffusion. On the other hand, adoption subsidies do not provide incentive to save energy compared to pollution taxes. Moreover, adoption subsides or tax credits requite large government expenditures (Jaffe et al., 2004). Providing subsidy funds implies welfare losses in the second best world, since the government is reliant on distortionary taxes. For example, Parry (1998) shows that the revenue-financing effect – the welfare costs arising from financing subsidies via increase in labour taxes – is typical larger than the tax-interaction effect – the welfare gain resulting from higher labour supply driven by increasing in the real wage. Finally, Mulder (2005) shows also that investment subsidies cannot be effective because they can induce effects of lock-in relative to inferior technologies in the long-run.

### 3.1.3 Environmental Policy and Innovation

There is theoretical and empirical evidence regarding the relationship between energy prices and innovation, i.e., price induced technological change. The hypothesis of price induced innovation was firstly introduced by Hicks (1932), who argues that high factor prices encourage innovation. Following Hicks (1932), the hypothesis of price induced innovation was also applied by Newell et al. (1998) to explain the relationship between energy prices and innovation of energy saving technologies. Furthermore, Popp (2002) shows that both energy prices and the quality of existing knowledge can significantly encourage the innovation process. Using U.S. patent data from 1970 to 1994, he found that environmental taxes and command-control instruments can reduce not only pollution by shifting away to less polluting activities, but also encourage the development of new technologies which are more cost-effective in the long term. Moreover, Goulder and Schneider (1999) emphasize that the existence of price-induced technological change may imply lower costs of environmental policy.

There are various policy instruments, such as environmental taxes, tradable emission permits, adoption subsidies, subsidies for research, and performance standards, which all can be used for pollution regulation. The choice of an appropriate one (or a combination of these) is not a trivial task since different policy objectives, such cost effectiveness, environmental effectiveness, and income equity, should be covered. The criterion for cost effectiveness suggests that the marginal abatement costs should be equalized among all polluters. Parry and Goulder (2008) conclude that i) no single policy instrument can be defined as superior compared to others, ii) the choice of a certain instrument typical raises a trade off between different policy objectives, such as efficiency, political feasibility, and income equity, iii) a combination of instruments can be desirable in the presence of market failures, and iv) there can be overlapping between policy instruments.

## 3.2 Optimal Environmental Taxation

### 3.2.1 Double Dividend Hypothesis

Property rights cannot be defined for environmental goods due to their non-exclusive and non-rival nature so that there are no markets for environmental goods, resulting in an inefficient allocation of resources (Helfand et al., 2003). Negative environmental externalities arising from production and usage of environmental goods can be internalized by using environmental taxes, i.e., Pigouvian taxes. The analysis of optimal commodity taxation in the presence of externalities was pioneered by Sandmo (1975), who modified the Ramsey rule for optimal taxation (Ramsey, 1927) by incorporating external effects. Compared to other abatement polices to combat climate change such as carbon quotas and grandfathered carbon permits, environmental taxes provide a revenue-raising benefit – called as Ramsey component in taxation literature – which can increase welfare. Revenue-raising abatement policies tend to be more efficient compared to command administrative instruments, especially in the presence of pre-existing distortions (Parry, 1997; Goulder, 1998; Parry et al., 1999). Moreover, market-based instruments are typical more efficient for emission abatement since these equalize marginal abatement costs among emission sources.

According to the environmental taxation literature, an introduction of environmental taxes is often related to the double dividend hypothesis. The hypothesis claims that substituting environmental taxes for other distortionary taxes benefits not only the environment, but also reduces efficiency costs of the tax system (e.g. Oates, 1995). “Weak” and “strong” double dividend hypotheses are distinguished. The relatively uncontroversial “weak” double dividend hypothesis suggests 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. The more ambiguous “strong” double dividend hypothesis argues that not only the environment can be improved, but also inefficiencies of the tax system can be alleviated (Goulder, 1995). It should be noted that the term “double dividend” in some studies is defined in terms of employment and other in terms of welfare. This can induce some confusion with respect to the definition what a double dividend is. According to Bosello et al. (1999), all studies of the double dividend hypothesis can be divided into two categories: 1) studies that analyse a double dividend in terms of welfare, and 2) studies that analyse a double dividend in terms of employment.

Important aspects of the double dividend hypothesis are summarised as follows:

1) **Environmental taxes and pre-existing tax distortions.** Parry (1995) and Goulder et al. (1997) find that substituting environmental taxes for labour taxes exacerbates pre-existing distortions from labour taxation. The intuitive explanation behind this is that narrow-based taxes (pollution taxes) induce a larger marginal excess burden compared to broad-based taxes (income taxes) because under narrow-based taxation implies a wide range of substitution possibilities (Parry and Oates, 2000). In addition, Bovenberg and Goulder (1996) show that the optimal pollution tax typically falls short of the Pigouvian tax in the presence of tax distortions in the labour market. This means that substituting pollution taxes for labour taxes exacerbates pre-existing distortions rather than alleviating such distortions.

2) **Non-separable environmental effects.** Williams (2002; 2003) analyses the link between pollution, human health, and labour productivity. By using a modified version of the model developed by Parry et al. (1999), he shows that a reduction in pollution, resulting from the introduction of a pollution tax, can have different economic effects. i) Reductions in pollution can improve health, resulting in higher labour productivity. This induces additional benefit, a *benefit-side tax-interaction effect,* which can offset the negative tax-interaction effect under certain conditions. ii) If a reduction in pollution leads to higher fixed-factor productivity or less medical expenses, the environmental tax reform would lead to a welfare loss. iii) If a reduction in pollution is associated with less time lost in illness, the net welfare effect of the environmental tax policy can be either positive or negative.

3) **Production externalities.** Bovenberg and de Mooij (1997) use a simple endogenous growth model to examine the link between environmental taxes and endogenous growth. They find that substituting pollution taxes for output taxes can encourage economic growth in the presence of strong environmental production externalities.

4) **Substitution between consumption and environmental quality.** Schöb (2003) shows that, in the presence of substitutability between taxed consumption goods (defensive goods) and the environmental quality, welfare losses are lower compared to those without substitutability. This is because welfare costs are partially compensated by higher tax revenues from the increased demand for taxed clean goods.

5) **Tax deductions.** Parry and Bento (2000)[2] show that welfare gains from substituting environmental taxes for labour taxes can be substantially larger when tax-favoured consumption (e.g. housing and medical care) is introduced in the model. The tax-favoured consumption is defined as the consumption, spending on which is fully (or partially) deducted from labour taxes so that labour taxes distort not only the labour market, but also the choice among consumption goods.

6) **Tax shifting effect.** Bovenberg and Goulder (2002) point out that if the initial tax system is inefficient, the introduction of environmental taxes can reallocate the burden of taxation, making the tax system more efficient. They also state that the welfare cost of an environmental tax reform will be lower if i) the applied tax instruments differ strongly with respect to their marginal efficiency costs, ii) the burden of environmental taxation shifts to the factor, whose taxation has relatively low marginal efficiency

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[2] For another special case, see Parry and Bento (2001).

costs, and iii) revenues from environmental taxes are refunded through a reduction of tax rates of a factor, whose taxation has high marginal efficiency costs.

7) **Tax-shifting effects: capital and labour.** De Mooij and Bovenberg (1998) find that in the presence of capital, in the short and medium term, an environmental tax reform can induce the so-called tax-shifting effect between factors. Intuitively, if the reform shifts the tax burden from the overtaxed factor to the undertaxed factor, this can alleviate the pre-existing inefficiency of the tax system. For example, if capital is internationally mobile, substituting environmental taxes for capital taxes can yield a double dividend, or if capital is internationally immobile, substituting environmental taxes for labour taxes can reduce efficiency costs of the tax system. In the long-run, however, capital is quite mobile, which implies elastic supply of capital. Therefore, under the assumption of international capital mobility in the long term, substituting environmental taxes for labour taxes exacerbates initial inefficiencies in the tax system. The main factor with respect to the tax-shifting between labour and capital is the initial burden of labour taxation relative to capital taxation. In reality, capital is neither perfectly mobile nor perfectly immobile across countries. One of the plausible explanations for international capital immobility is asymmetric information across countries (Gordon and Bovenberg, 1996).

8) **Tax-shifting effect: natural resources.** Apart from capital, natural resources can also be considered as a fixed factor. For example, Bento and Jacobsen (2007) show that in the presence of a fixed factor and untaxable Ricardian rents, an environmental tax reform can induce a double dividend since the burden of environmental taxes is borne not only by labour, yet it is also borne by natural resources in terms of lower prices of natural resources (i.e., Ricardian rents). This conclusion is based on these drawn in the previous papers such as Perroni and Whalley (1998). They find that the existence of natural rents (Ricardian rents) reduces the cost of taxation, whereas market structure rents arising from imperfect competition increase this. This conclusion suggests that commodity taxes should be high on commodities, whose production involves a fixed factor. Intuitively, commodity taxes operate like implicit taxes on profits (rents) in the absence of an explicit profit tax.

9) **Tax-shifting effect: net return on investment and profits.** Bovenberg and de Mooij (1997) find that substituting pollution taxes for output taxes can reduce efficiency costs of the tax system in shifting the burden of taxation from the net return on

investment towards profits, where the most important factor for a strong tax shifting effect is low substitutability between physical capital and pollution. The intuitive explanation behind this is that pollution taxes operate like implicit taxes on profits (rents) so that additional revenues from pollution taxes allow for larger reduction in distortionary output taxes. It should be noted that an economic profit under perfect competition occurs typically in the presence of a fixed factor.

10) **Magnitude of the tax-shifting effect.** According to Bovenberg and van der Ploeg (1996; 1998) important conditions under which an environmental tax reform can increase employment in the presence of a fixed factor are the following: i) low initial tax rates on resources, ii) a large production share of the fixed factor, and iii) high substitutability between labour and resources.

11) **Production structure.** The production structure can significantly impact the tax-shifting effect between labour and a fixed factor, thereby affecting employment. Bovenberg and van der Ploeg (1998) analyse three separable production functions, where each production function includes three factors: resources, labour and a fixed factor. The findings are the following. i) If resources are separable from the aggregate of labour and the fixed factor in the production function, and substitution between resources and the value added aggregate is high (low), substituting environmental taxes for labour taxes tends to reduce (increase) the employment. ii) In the case of separability between labour and the aggregate of resources and the fixed factor, an increase in employment is likely if substitution between resources and the fixed factor is low as well as substitution between labour and the aggregate of resources and the fixed factor is high. iii) If the fixed factor is separable from the aggregate of labour and resources, substituting environmental taxes for labour taxes leads to an increase in employment if the elasticity of substitution between the fixed factor and the aggregate of labour and resources is small.

12) **Substitution between consumption and leisure.** The tax burden effect, *inter alia*, depends on substitution between private consumption and leisure. A high elasticity of substitution between private consumption and leisure implies a strong tax burden effect. This is because a high elasticity of substitution leads to a strong reduction in private consumption. A high elasticity of substitution between labour and polluting goods as well a large share of resources implies a strong tax shifting effect (Bovenberg and van der Ploeg, 1996).

13) **Tax-shifting effects: terms of trade.** Furthermore, there are other types of tax-shifting effects which can lead to a double dividend, such as tax-shifting across countries (i.e., the terms of trade effect) and tax-shifting among household incomes. For example, Killinger (2000), de Mooij (2000) and Krutilla (1991) show that the burden of environmental taxation can be partially shifted to foreign suppliers through a terms-of-trade effect. This, however, is feasible only for large economies which can affect the world market price.

14) **Tax-shifting effect: intertemporal inefficiencies.** Fernandez et al. (2011) using a stylized dynamic general equilibrium model with endogenous growth show that substituting environmental taxes for income taxes can yield a double dividend, if the current tax system is intertemporal inefficient with respect to the income taxes. If intertemporal inefficiencies of income taxes are visible, a change in the income tax rate over time by using debt issuing can enhance the welfare. The main feature of the model is the incorporated debt issuing so that the burden of environmental taxation can be shifted from the present to the future.

15) **Environmental policy and labour markets.** Ligthart and van der Ploeg (1999) show that in the case of a downward-sloping labour supply curve, an increase in the labour tax is refunded in favour of public abatement activities can lead to a double dividend under certain conditions.[3] The intuition behind this is that lower wages resulting from higher labour taxation will drive households work more to satisfy their subsistence consumption.

One of the most important lessons which can be derived from the theoretical literature on environmental taxation is that environmental taxes are implicit taxes on production factors so that increasing environmental taxes raise the pre-existing tax distortions (Bovenberg and Goulder, 2002). On the other hand, inefficiencies in the tax system provide possibilities for a strong double divided (Parry, 1998). In particular, a strong tax-shifting effect is a necessary condition for the occurrence of a strong double dividend (de Mooij, 2000). On grounds of economic efficiency, it is likely more efficient to reform the tax system directly in order to alleviate such inefficiencies, rather than indirectly via an environmental tax reform; however, there may be strong political opposition (Parry and Bento, 2000). In general, the occurrence of the strong double-dividend is ambiguous. The outcome, *inter alia*, depends on the tax and

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[3] Upward slopping labour supply curve is the curve where the substitution effect between work and leisure dominates the income effect, which is indicated by positive uncompensated wage elasticities. Backward sloping (downward sloping) labour supply curve is the curve where the income effect overweight the substitution effect (Ligthart and van der Ploeg, 1999).

economic structure, household preferences, factor mobility, factor substitution, and revenue recycling strategies (Goulder, 2002). Fullerton and Gravelle (1999) point out that the theoretical literature on the double dividend hypothesis does not provide a clear answer since this is based on strong assumptions so that an empirical evaluation of the double dividend hypothesis becomes crucial. Hence, general equilibrium analysis is an appropriate analytical method (Goulder, 2002).

**Empirical evidence.** Some European countries have already implemented an environmental tax reform, where an introduction of various environmental taxes (carbon dioxide or sulphur dioxide) is compensated by reductions either in personal income taxes or social security contributions. Bosquet (2000) reviewed 139 modelling simulations with respect to an environmental tax reform. The main finding is that positive employment and welfare effects are likely in the short and medium term, whereas in the long run the effect are less certain. In addition, Bosquet (2001) argues that, under certain conditions, an implementation of such environmental tax reform in Russia can simultaneously achieve environmental and economic gains. Pauelli et al. (2005) investigate the studies on environmental tax reform by using a quantitative meta-analytic approach. They show that an environmental tax reform typically leads to higher employment (employment double dividend), while the occurrence of a strong double dividend in terms of welfare is ambiguous.[4]

Empirical studies reviewed by Bosquet (2000) and Pauelli et al. (2005) and Bosello et al. (1999) and Bovenberg and Goulder (2002) deal with empirical studies which were carried out until 2000. Some more recent empirical studies on the double dividend issue are reviewed below (Table 3.1). Many studies are based on the assumption of international capital immobility while this study also considers the introduction of carbon taxes under international capital mobility, which is shown to influence strongly the results.

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[4] For other surveys on employment double dividend see Bosello et al. (1999) and Bovenberg and Goulder (2001).

## Table 3.1: Empirical Studies on Double Dividend Hypothesis

| Authors | Country | Model | Policy simulation | Special assumptions[5] | Effects |
|---|---|---|---|---|---|
| Bor and Huang (2010) | Taiwan | Dynamic single-country multi-sector CGE model | Substituting energy taxes for individual income taxes and business income taxes. | n.a. | Positive GDP growth |
| Takeda (2007) | Japan | Dynamic single-country multi-sector CGE model | Substituting a carbon tax for capital income taxes, labour income taxes and consumption taxes. | n.a. | A strong double dividend arises only if revenues from the carbon tax are refunded through a reduction in the capital tax. |
| Heerden et al. (2006) | South Africa | Single-country multi-sector comparative static CGE model | Four environmental taxes are analysed: i) a tax on GHG emissions, ii) a fuel tax, iii) a tax on electricity, and iv) a tax on energy use. Revenues are refunded in a reduction in i) tax on factor income, ii) consumption taxes and iii) consumption taxes on food. | Unemployment in the unskilled labour market is assumed. Capital is assumed to be immobile across sectors. | There is a triple dividend – reductions in emissions and poverty as well as an increase in GDP – in case when revenues from environmental taxes are refunded through a reduction in the consumption tax on food. |
| Babiker et al. (2003) | Global economy | Recursive dynamic multi-regional CGE model (EPPA) | Carbon permits are introduced to achieve Kyoto agreement. The following recycling scenarios are considered: i) lump-sum recycling, ii) labour tax recycling, iii) non-energy consumer tax recycling, and iv) 50% labour and 50% consumer tax recycling. | Labour-leisure choice is incorporated into the model. Factor and consumption taxes are introduced in the database. | i) The weak double dividend is unlikely to hold for a number of European countries. ii) Results differ by region depending on the tax system. In particular existing energy policy has a significant impact on the results. |
| Manresa and Sancho (2005) | Spain | Single-country multi-sector comparative static CGE model | Substituting an ecotax and a petrol tax for payroll taxes. | Wage rigidity and unemployment are incorporated. | Under certain conditions, a triple dividend can occur: i) reduction in unemployment, ii) lower emissions, and iii) non- |

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[5] The "standard" assumptions are perfect competition in output and factor markets, international immobility of capital and labour, constant return to scale in production, the Armington specification of domestic demand, production is typically modeling by using nested CES function with substitution between labour, capital, and energy.

| | | | | | |
|---|---|---|---|---|---|
| | | | | | environmental welfare gains. |
| Glomm et al. (2008) | USA | Dynamic inter-temporal single-country single-sector CGE model | Substituting gasoline taxes for capital taxes. | n.a. | A double dividend in terms of welfare ("efficiency" dividend) is feasible under certain conditions, yet this can come on account of the first dividend. |
| Saveyn et al. (2011) | EU | Recursive dynamic multi-country multi-sector CGE model (GEM-E3) | Copenhagen Accord is implemented. Four options for the allocation of permits are considered: i) free allocation in EU, ii) auctioning only in the power generation sector in EU, iii) auctioning in all energy intensive sectors in EU, and iv) auctioning in energy intensive sectors and tax for non-energy intensive sectors in EU. | Labour-leisure choice is incorporated into the model. | Increases in the GDP arise if revenues from auctioning of permits and GHG taxation are recycled through a reduction in social security contributions. |
| Bach et al. (2002) | Germany | Two macroeconomic models are employed: an econometric input-output model (PANTA RHEI) and a dynamic CGE model (LEAN). The distributional impacts of policy simulations are analysed by using a micro-simulation model of households. | An excise tax is introduced on usage of fuel oil, gasoline, diesel oil, electricity and natural gas. Several tax differentiation and tax exemptions are implemented. Revenues from energy taxes are recycled via a reduction in social security contributions. | n.a. | The environmental fiscal tax reform results in an employment double dividend, where $CO_2$ emissions are reduced and employment is increased. The positive employment effect is rather moderate. |

Source: Own compilation.

### 3.2.2 Environmental Taxation under Imperfect Competition

One of the central questions raised in the environmental taxation literature is whether the second best optimal environmental tax rate is higher or lower than the Pigouvian one in the presence of pre-existing distortions. In a first best world, the optimal environmental tax rate equals the marginal social damage, i.e., the so-called Pigouvian tax (Carlsson, 2000). Under a second best setting, the design of environmental tax policy can be much more complicated. For instance, Bovenberg and Goulder (1996)[6] show that in the presence of distortionary taxes in the labour market, the optimal environmental tax rate is generally below the Pigouvian tax rate. Furthermore, if polluters are imperfectly competitive, there can be a trade-off between the two distortions, one due to suboptimal production (underproduction), and the other due to externalities.

**Analytical model.** Using a partial equilibrium model developed by Stern (1987), the effects of environmental taxes on output, emissions, profits and number of firms are summarized.[7] Moreover, the second best optimal pollution tax is derived. The model is a Cournot oligopoly with homogenous products and symmetric firms. Equation (3.2.1) defines the first order condition for profit maximization, which implies that marginal revenue equals marginal cost:

$$p\left(1-\frac{\gamma}{\varepsilon}\right)-c=0\,, \tag{3.2.1}$$

where $p$ is the price, $\gamma=\alpha+\left[\frac{(1-\alpha)}{n}\right]$, $\alpha$ is the parameter for conjectural variation (a Cournot Nash assumption implies that $\alpha$ =0), $n$ is the number of firms, $c$ is the marginal cost, and $\varepsilon$ is the elasticity of demand. Equation (3.2.2) defines profit ($\Pi$):

$$\Pi=(p-c)X(p)-kn\,, \tag{3.2.2}$$

where $X(p)$ is demand function for aggregated output and $k$ is fixed costs. The industrial level of emissions ($E$) is defined by equation (3.2.3):

$$E=E(X)\,, \tag{3.2.3}$$

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[6] Fullerton (1997) showed that (i) in the absence of labour taxes, the tax on the dirty good could exceed the Pigovian rate. Moreover, if the tax on the dirty good is zero, a higher tax on labour and a subsidy on the clean good can achieve the same outcome as the dirty tax. See also Bovenberg and de Mooij (1997)

[7] The same conclusions were drawn by Stern (1987) with respect to commodity taxation under a Cournot oligopoly.

where $E_X$ >0[8]. Equation (3.2.4) defines the stability condition (Seade, 1987):

$$1-\frac{\gamma}{\varepsilon}+\frac{F\gamma}{\varepsilon}>0, \tag{3.2.4}$$

where $F$ is *the elasticity of the elasticity of demand*: $F=\frac{p\varepsilon_p}{\varepsilon}$ and $\varepsilon_p$ is the derivate of $\varepsilon$ with respect to *p*. The term on the LHS of equation (3.2.4) should be strictly positive. The stability condition is useful to recognize the sign of several derivations below. Using this analytical framework, the following propositions can be derived.

**Proposition 1.** *Introducing a pollution tax leads to a reduction in output.*

**Proof.** Introducing pollution taxes results in higher production costs. Therefore, changes in production costs reflect an introduction of pollution taxes. Totally differentiating equation (3.2.1) with respect to *c*, we obtain:

$$\frac{dp}{dc}=\frac{1}{\left[1-\frac{\gamma}{\varepsilon}+\frac{F\gamma}{\varepsilon}\right]}. \tag{3.2.5}$$

Since $\frac{dX}{dc}=X_p\frac{dp}{dc}$, we obtain:

$$\frac{dX}{dc}=\frac{X_p}{\left[1-\frac{\gamma}{\varepsilon}+\frac{F\gamma}{\varepsilon}\right]}<0, \tag{3.2.6}$$

which is negative because $X_p$<0 and $\left[1-\frac{\gamma}{\varepsilon}+\frac{F\gamma}{\varepsilon}\right]$>0 according to the stability condition (3.2.4). Since the term is negative, introducing pollution taxes unambiguously induces a reduction in output. **Q.E.D**.

**Proposition 2.** *Introducing a pollution tax leads to a reduction in emissions.*

**Proof.** $\frac{dE}{dc}$<0 because $\frac{dX}{dc}$<0 and $E_X$>0. **Q.E.D**.

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[8] For convenience, partial derivates of functions are noted as suffixes: for example, $E_X=\frac{\partial E}{\partial X}$, $X_p=\frac{\partial X}{\partial p}$, $E_c=\frac{dE}{dc}$ and $X_c=\frac{dX}{dc}$.

**Proposition 3.** *Introducing a pollution tax leads to a reduction (increase) in profit if demand is elastic (inelastic) in case of isoelastic demand.*

**Proof.** Totally differentiating equation (3.2.2) with respect to $c$ and replacing $\frac{dp}{dc}$ by the term in the RHS of equation (3.2.5), we obtain: [9]

$$\frac{d\Pi}{dc} = \frac{-X\gamma\left[1-\frac{1}{\varepsilon}+\frac{F}{\varepsilon}\right]}{\left[1-\frac{\gamma}{\varepsilon}+\frac{F\gamma}{\varepsilon}\right]} < > 0, \tag{3.2.7}$$

where $\left[1-\frac{\gamma}{\varepsilon}+\frac{F\gamma}{\varepsilon}\right]$>0, $\gamma$>0, $\left(-X\right)$<0. Therefore, $\frac{d\Pi}{dc}$<0 iff $F$>1-$\varepsilon$. In case of isoelastic demand, which implies $F$=0, $\frac{d\Pi}{dc}$<0 iff $\varepsilon$>1 and vice versa. **Q.E.D**.

**Proposition 4.** *Introducing a pollution tax leads to a reduction (increase) in the number of firms if demand is elastic (inelastic) in case of isoelastic demand.*

**Proof.** Equation (3.2.2) is replaced by equation (3.2.8), where profit equals zero and the number of firms is variable under the assumption of free entry and exit:

$$(p-c)X(p) - kn = 0. \tag{3.2.8}$$

Totally differentiating equation (3.2.1) and (3.2.8), we obtain the following system of equations:

$$dp(X+\gamma X) - kdn = Xdc; \tag{3.2.9}$$

$$dp\left(1-\frac{\gamma}{\varepsilon}+\frac{\gamma}{\varepsilon}F\right)+\frac{p}{\varepsilon}\frac{(1-\alpha)}{n^2}dn = dc; \tag{3.2.10}$$

or in matrix form:

$$\begin{bmatrix} (X+\gamma X) & -k \\ \left(1-\frac{\gamma}{\varepsilon}+\frac{\gamma}{\varepsilon}F\right) & \frac{p}{\varepsilon}\frac{(1-\alpha)}{n^2} \end{bmatrix}\begin{bmatrix} dp \\ dn \end{bmatrix} = \begin{bmatrix} X \\ 1 \end{bmatrix} dc \tag{3.2.11}$$

Solving this system of equation for $\frac{dn}{dc}$ yields:

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[9] For convenience, the demand function is written without arguments, i.e. *X* instead of *X(p)*.

$$\Delta\frac{dn}{dc} = X(1-\gamma) - X\left[1-\frac{\gamma}{\varepsilon}+\frac{\gamma}{\varepsilon}F\right], \tag{3.2.12}$$

where $\Delta = (X - \gamma X)\frac{p}{\varepsilon}\frac{(1-\alpha)}{n^2} + k\left(1-\frac{\gamma}{\varepsilon}+\frac{\gamma}{\varepsilon}F\right) > 0$. Therefore, $\frac{dn}{dc}$<0 iff $F$>1-$\varepsilon$. In case of isoelastic demand, which implies $F$=0, $\frac{dn}{dc}$<0 iff $\varepsilon$>1 and vice versa. **Q.E.D**.

**Proposition 5.** *Second best optimal pollution tax rate falls short of marginal social damage.*

**Proof.** Using this analytical framework, we can derive the second best optimal pollution tax rate as follows. Equation (3.2.13) defines the consumer welfare (W):

$$W = \int_0^X P(x)x - cx - E(x), \tag{3.2.13}$$

where $P(x)$ is an inverse demand function for aggregated output.[10] Totally differentiating function (3.2.13) with respect to $t$, we obtain:

$$\frac{dW}{dt} = \frac{dx}{dt}(P - c - E_X) = 0, \tag{3.2.14}$$

where $\frac{dW}{dt} = 0$ is the condition for an optimal tax rate. Profit function (3.2.2) is modified by adding a pollution tax (t):

$$\Pi = (P(x) - c)x - xt - kn \tag{3.2.15}$$

Differentiating profit function (3.2.15) with respect to $x$ yields: [11]

$$P - c = t - xP_X. \tag{3.2.16}$$

Substituting (3.2.16) into (3.2.14), we obtain:

$$\frac{dx}{dt}(t - xP_X - E_X) = 0. \tag{3.2.17}$$

Dividing the both side by $\frac{dx}{dt}$, the second best optimal pollution tax rate is defined as follows:

$$t = E_X + xP_X. \tag{3.2.18}$$

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[10] Since the price is introduced as an inverse demand function, a capital letter is used. In contrast, independent variables are written in small letters.

[11] For convenience, the inverse demand function is written without arguments, i.e. *P* instead of *P(x)*.

From equation (3.2.18) we can see that the second best optimal pollution tax rate falls short of marginal social damage ($E_X$) by the term ($xP_X$). Note that $P_X$ <0. **Q.E.D**. This confirms conclusions drawn by Ebert (1992).

**Other aspects.** The main findings regarding environmental taxation under imperfect competition from other studies are summarized as follows:

1) **Distortions from imperfect competition.** If polluters are imperfectly competitive, there can be a trade-off between the two distortions, one due to suboptimal production (underproduction), and the other due to negative externalities. A pollution tax can reduce external damages, but it can also lead to a reduction of an already suboptimal production level (Buchanan, 1969). Barnett (1980) and Misiolek (1980) formally show that the second best optimal environmental tax rate for monopolistic polluters is typically less than marginal social damage. Ebert (1992) draws the same conclusion for the case of oligopolistic polluters. Generally, under the assumption of symmetric firms and blocked entry/exit, the second best optimal tax rate falls short of the marginal social damage.

2) **Asymmetry in production costs.** In contrast, Simpson (1995) argues that the optimal environmental tax rate can exceed the marginal social damage under an imperfectly competitive market structure, if firms have different production costs. The intuition behind this is that a pollution tax can shift production from less to more efficient firms.

3) **Asymmetry in pollution and production costs.** The importance of firms' asymmetry was also stressed by other authors. For example, Levin (1985) and Sugeta and Matsumoto (2005) show that due to asymmetry in pollution and production costs, environmental taxes might even induce increases in pollution through a reallocation of output across firms.

4) **Inefficiencies from excessive entry.** Katsoulacos and Xepapadeas (1995) and Lee (1999) show that environmental taxes can also have a corrective effect regarding the market structure, by limiting the number of firms to a social optimum. The intuition behind this is that homogeneous product oligopolies have a tendency towards an excessive entry of firms (Mankiw and Whinston, 1986). Therefore, an over-internalisation can reduce the distortion arising from an excessive number of firms. Requate (1997) and Sugeta and Matsumoto (2005) show that the optimal

environmental tax can exceed the marginal damage cost in case of a strictly concave demand.

5) **Positive externalities.** Moreover, Yin (2003) demonstrates that the optimal environmental tax can exceed the marginal social damage, if a reduction in emissions leads to a significant decline in marginal costs of other producers in the presence of positive inter-firm externalities.

### 3.2.3 Environmental Taxation and Distributional Effects

Apart from economic efficiency, another important political concern associated with carbon taxes is a distributional impact of taxation. The main concern with respect to environmental taxation is that it tends to be regressive since the burden of taxation is expected to fall disproportionately on poor households (Hassett et al., 2009). Fullerton (2011) defines six distributional effects arising from a carbon permit system, which are summarized as follows.

1) **Uses-side incidence.** He distinguishes between the “uses-side” and “source-side” incidence of an environmental tax. The uses-side incidence represents the first distributional effect of an environmental tax. This is defined as an effect on income distribution via changes in commodity prices. The uses-side incidence of environmental taxation is typically regressive (Fullerton and Heutel, 2010).

2) **Source-side incidence.** The source-side effect defines a distributional impact via changes in factor prices. For instance, polluting industries are often capital intensive so that the source-side incidence can be progressive, if capital is a more important income source for rich households compared to poor households. This is because introducing environmental taxes is expected to lead to a lower return to capital relative to wage. Nevertheless, the source-side incidence can be regressive under certain conditions.

3) **Scarcity rents.** A reduction in output of polluting goods provides scarcity rents. If the government levies a pollution tax or carries out an auction of permit, then the scarcity rents are captured by the government in terms of high revenues from pollution taxes. Otherwise, polluting firms receive the scarcity rents from selling restricted quantities (e.g. Buchanan and Tullock, 1975; Bovenberg and Goulder, 2000).

4) **Effects of improvement in environmental quality.** Climate policy can have various distributional effects. For example, more environmental concern will reduce global warming. This will be beneficial especially for the poorest counties. This is because

reductions in global warming are associated with higher agricultural productivity in the poorest countries with high temperature.

5) **Transition costs.** Labour and capital are often assumed to be perfectly mobile among sectors so that they have the same return. In a real economy, a reallocation of production factors from one sector to another could result in large adjustment costs since production factors can have different productivities. For example, an environmental tax reform can have an adverse effect on employment. Therefore, adjustment costs arising from environmental policy should also be taken into account.

6) **Capitalization effects.** Environmental improvement (air quality improvement) could lead to benefits not to low-income renters, but to landlords who own the house because of increasing rents.

Substitution between pollution and production factors has a significant impact not only on the economic efficiency of an environmental tax reform, but also on the income distribution. Fullerton and Heutel (2007) analyse the incidence of environmental taxes by using a simple general equilibrium model which was developed by Harberger (1962). The main findings are the following. i) Introducing carbon taxes raises the wage relative to the return to capital, if substitution between labour and pollution is higher than that between capital and pollution, or if the polluting sector is capital intensive. In other words, the “substitution effect” induces less tax burden on a factor which is easier substitutable with pollution, whereas the “output effect” places more tax burden on a factor which is more intensively used in the polluting sector (Fullerton, 2011)[12]. ii) Numerical sensitive analyses suggest that the impact of elasticities of substitution between pollution, capital and labour is more important than the impact of factor intensities.[13]

Ekins et al. (2011) review empirical studies on distributional effects of environmental taxes. They conclude that environmental taxes typically have a regressive impact on households. Moreover, taxes on overall energy consumption by households tend to be strongly regressive, whereas taxes on petroleum products are sometimes progressive since poor households cannot afford cars. Despite the regressive impact of environmental taxes, their simulation results suggest that an environmental tax reform in Europe will lead to higher real income and will not be generally regressive.

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[12] The substitution effect is determined by elasticities of substitution between capital, labour, and pollution, whereas the output effect is determined by factor intensity.

[13] For some special cases see Fullerton and Heutel (2007).

Furthermore, West and Williams (2004) examine the distributional effects of a gasoline tax. They find that a gasoline tax is regressive, if revenues from the gasoline tax are not recycled. The gasoline tax can be significantly less regressive, if revenues are refunded through a reduction in labour taxes, whereas the gasoline tax can be even progressive, if gasoline tax revenues are returned to households in lump-sum form. Metcalf (1999; 2009) states that an environmental tax can be regressive, yet an environmental tax reform can be progressive depending on revenue recycling strategies. Moreover, Rausch et al. (2011), using a multi-region and multi-sector CGE model with incorporated 15,588 households from the U.S. Consumer and Expenditures Survey data, found that the source-side incidence of carbon taxes can be sufficiently progressive to offset the regressive uses-side incidence.

### 3.2.4 Environmental Tax Differentiation

The theoretical literature on commodity taxation suggests a principal of uniform taxation so that tax rates should be uniform between sectors and households. The theory of environmental taxation also follows this principle. Nevertheless, there are some cases where an environmental tax differentiation may be more desirable on grounds of economic efficiency and income distribution (Rutherford and Böhringer, 2002):

1) **Tax interaction.** In the presence of pre-existing tax distortions, it may be rational to differentiate the environmental tax rates among industries and households to correct inefficiencies of the tax system.

2) **Distributional concern.** Lower tax rates (or even exemptions) can be applied for certain poor household groups to alleviate a regressive impact of environmental taxation. Alternatively, tax rates can be uniform among households, yet the government can correct the regressive effect resulting from the introduction of environmental taxes by using different revenue recycling strategies (Metcalf, 1999).

3) **Carbon leakage.** Environmental concerns in the home country can lead to a reallocation of domestic production to other countries so that emissions abroad can rise. A numerical analysis carried out by Böhringer (1998) by using a multi-region CGE model shows that a differentiation in carbon tax rates (or even exemption from taxation) for some specific sectors can diminish carbon leakage, but the welfare costs of such an environmental policy tend to be higher compared to those under uniform taxation.

4) **Terms of trade effects.** In the absence of trade policy, the government can impose different environmental tax rates to improve its terms of trade so that environmental taxes operate like proxies for optimal export and import taxes (e.g. Krutilla, 1991).

Nevertheless, some empirical analyses state that there is not much economic rationality for a strong tax preference for energy intensive sectors (e.g., Rutherford and Böhringer, 2002).

In the absence of administrative and compliance costs of taxation, the first best policy would be a targeted tax on an emission since this would provide a behavioural response to avoid the emission by implementing abatement measures (technologies). For example, Devarajan et al. (2011) show that the introduction of a carbon tax leads to less marginal costs of abatement compared to when energy taxes are levied. In contrast, if administrative costs of a targeted taxation are substantial, an indirect tax (a broad based tax) may be more efficient because its implementation is typically associated with less administrative costs, yet this is not so efficient in providing the "right" behavioural incentives compared to a targeted tax (e.g. Smulders and Vollebergh, 2000). Schmutzler and Goulder (1997) examine how monitoring costs, input and output substitution possibilities can affect the design of optimal environmental taxation. They, *inter alia*, state that an output tax can be more desirable under i) high monitoring costs, ii) small input substitution, and iii) high output substitution. Furthermore, a combination of different policy instruments can be rational, so-called two part instruments. For example, Eskeland and Devarajan (1996) show that a combination of environmental standards and a tax on polluting inputs (e.g. excise tax) may operate as a targeted environmental tax. Fullerton and Wolverton (1997) examine the equivalence between a Pigovian tax and a tax-subsidy combination. A tax-subsidy combination includes an environmental tax on all polluting activities, whereas an environmental subsidy is imposed on clean technologies. They also point out that a tax-subsidy combination can be easier implemented than the Pigouvian tax.

## 3.3 Summary of the Chapter

The replacement of technologies could be slow due to non-market failure – underestimation of adoption costs, high discount rates, and heterogeneity of energy users – and market failures – lack of information, principle-agent problems, and low energy prices because of inefficient price regulation and non-internalized environmental externalities. On ground of economic efficiency, only the existence of market and behavioural failures can provide justifications for government intervention. As shown in Chapter 2, the replacement of technologies in Russia is particularly slow due to a combination of non-market failures and market failures. This analysis is focused on non-internalized environmental externalities as a reason for high GHG emissions and slow technological replacement in Russia.

Environmental taxes are one of the powerful instruments to encourage the diffusion of energy saving technologies. Compared to other policy instruments, environmental taxes have an important advantage: they provide additional tax revenues. Furthermore, substituting environmental taxes for other distortionary taxes may reduce inefficiency of the tax system, i.e., a strong double dividend may occur. According to the theoretical and empirical literature, the occurrence of a strong double dividend is ambiguous since it depends on various factors such as the tax system, factor mobility, factor substitution and household preferences.

In this context, the following objectives of this analysis are derived: i) to test the double dividend hypothesis under perfect and imperfect competition in output markets in Russia, to analyse ii) the incidence of carbon taxes, iii) impacts on sectoral competitiveness, iv) effects on income equity, and v) interactions of carbon taxes with other taxes.

# 4 The Tax System and Tax Interactions

As shown in Chapter 3, the theoretical literature on environmental taxation is mainly focused on pre-existing distortionary taxes in the labour and capital markets, whereas interactions with other taxes such as trade taxes, value added taxes, excise taxes, and mineral resource extraction taxes are often neglected. At the same time, tax-interaction effects play a crucial role in determination the cost of an environmental tax reform. Chapter 4 starts with an overview of the Russian tax system, aims at recognizing the relevance of certain tax instruments. As it is shown below, export taxes on energy is an important source of government revenues in Russia. Therefore, the theoretical analysis of environmental taxation with respect to the double dividend issue is furthermore extended by addressing the interaction between environmental and export taxes on energy.

## 4.1 Structure of Government Revenues

As in other countries, the Russian economy is distorted by various taxes. This chapter gives a short overview of the Russian tax system, especially the tax regime which is applied to the production, consumption, and trade of energy commodities. Data on the tax system are taken from different legislative documents,[14] which were reviewed in March, 2012 and are summarised in Table 4.1.

**Table 4.1: Legislative Documents of the Russian Tax System**

| Taxes | Corresponding legislative documents |
|---|---|
| Value added tax, excise tax, corporate income tax, personal income tax, mineral resource extraction tax, and others | Russian Tax Code (second part) No.117-FZ from August 5th, 2000 (hereafter Russian Tax Code) |
| Export taxes on crude oil and oil products | Government Decree No. 695 from November 16th, 2006 |
| Export taxes on other commodities | Government Decree No. 88 from February 6th, 2012 |
| Import tariffs | Enactment No. 850 from November 18th, 2011 |
| Calculation of export taxes on crude oil | Law of Trade Tariffs No. 5003-1 from May 21st, 1993 |
| Calculation of export taxes on oil products | Government Decree No. 1155 from December 27th, 2010 |

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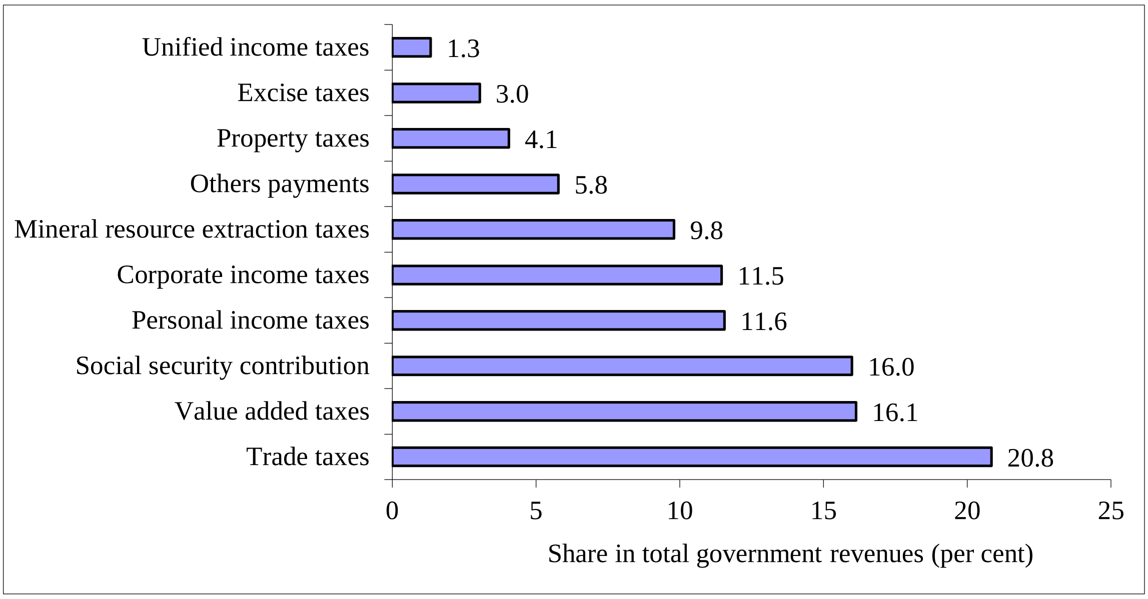
[14] All documents are available (in Russian) at http://www.consultant.ru/.

Figure 4.1 illustrates the structure of government revenues[15] in Russia in 2010. The largest source of government revenues – 20.8% of total government revenues – is from trade taxes, followed by value added taxes (16.1%), social security contributions (16.0%), personal income taxes (11.6%), corporate income taxes (11.5%), and mineral resource extraction taxes (9.8%). The magnitude of tax revenues depends on both tax bases and tax rates.

**Figure 4.1: Structure of Government Revenues in 2010 (per cent)**



**Unified income taxes** are taxes imposed according to the simplified tax system in Russia; **Others payments** are payments for the use of public property, free payments and others.
Source: FSSS (2012b).

## 4.2 Trade Taxes

In April, 2010 the *Customs Code of the Customs Union* (hereafter Customs Code) came into force. The Customs Code is a legislative document which regulates trade within the Customs Union as well as trade with non-members of the Customs Union. The Customs Union consists of the Republic of Belarus, the Republic of Kazakhstan, and the Russian Federation. It allows for free trade between Union members, whereas import tariffs are imposed on imports from non-Customs Union countries. According to the *Enactment No. 850 from November 18th, 2011*, there are high import tariffs on some food products, textile products, machineries, electronic equipment, and transports. For example, in 2012, there was a 15% import tariff on beef and pork and a 25% import tariff on sheep meat and poultry. Import tariffs on textile products, machineries, electronic equipment, and transports differ by product with tariff rates

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[15] A three-level budget system is applied in Russia: federal budget, regional budget, and local budget. The total government revenue is defined as the total revenue of the consolidated budget, which is a sum over federal, regional and local budgets.

varying between 5% and 30%. Import tariff rates on energy commodities excluding electricity were 5% in 2012.

High export taxes are imposed on commodities such as seeds, animal hide, timber, scrap metals, and energy resources. For example, according to *Government Decree No.88 from February 6th, 2012*, the rates of export taxes on seeds in 2012 were between 10% and 20%, 500 Euro/ton for raw animal hides, between 10% and 25%, or 100 Euro/$m^3$ for timber, and between 6.5% and 50% for scrap metals. Revenues from trade taxes consist mainly of export taxes on energy resources such as crude oil, oil products, and natural gas. For example, the revenue share of export taxes on crude oil was 52% of the total revenues from trade taxes in 2010, while for petroleum products it was 19% and for gas it was 6% (Roskazna, 2010). There are no export taxes on electricity and coal; however, an export tax on coke coal with a tax rate of 6.5% was introduced in 2007. Export taxes on crude oil and oil products are recalculated monthly by the Russian Government in accordance with changes in the price of Urals[16] oil (*Law of Trade Tariffs No.5003-1 from May 21st, 1993*). The tax rate is calculated according to the formula shown in Table 4.2.

**Table 4.2: Formula for the Calculation of Export Taxes on Crude Oil**

| Tax regimes | Formula |
|---|---|
| if $PW_{oil} < 109.5$ \$/ton | then $TE_{oil} = 0\%$ |
| if 109.5 \$/ton $< PW_{oil} <$ 146 \$/ton | then $TE_{oil} = 0.35*(PW_{oil} – 109.5$ \$/ton) |
| if 146 \$/ton $< PW_{oil} <$ 182.5 \$/ton | then $TE_{oil} =$ 12.77 \$/ton + $0.45*(PW_{oil} – 146$ \$/ton) |
| if $PW_{oil} > 182.5$ \$/ton | then $TE_{oil} =$ 29.2 \$/ton + $0.65*(PW_{oil} –182.5$ \$/ton) |
| where $PW_{oil}$ is the world price of Urals oil and $TE_{oil}$ is the rate of export taxes on crude oil. | |

Source: Law of Trade Tariffs No.5003-1 from May 21st, 1993.

The formula for the calculation of the export tax rate on crude oil includes four regimes. For example, the export price of Urals oil was 774 \$/ton since January 1st to May 1st, 2011 (Ministry of Economics, 2011). Since the export price ($PW_{oil}$) was higher than 182.5\$/ton, the specific export tax rate on crude oil ($TE_{oil}$) is calculated as follows:

$$29.2 \text{ \$/ton} + 0.65*(774 \text{ \$/ton} – 182.5 \text{ \$/ton}) = 413 \text{ \$/ton}.$$

Therefore, the rate of export tax on crude oil was approximately 413 \$/ton from January to May in 2011, which amounts to approximately 53% of the export price of Urals oil. Rates of export taxes on oil products depend on the export tax rate on crude oil. According to

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[16] Urals is an oil brand, whose prices are used to calculate export taxes on crude oil.

*Government Decree No.1155 from December 27th, 2010*, the rates of export taxes on oil products are calculated as follows:

$$TE_{petl} = K_{petl} * TE_{oil},$$

where $TE_{petl}$ are specific tax rates on oil products in \$/ton, $K_{petl}$ are multiplier coefficients, and $TE_{oil}$ is the specific export tax rate on crude oil in \$/ton. From 2003 to 2010, the multiplier coefficient was 0.9 for all oil products. Since 2010 coefficients differ among oil products (*Government Decree No.1155 from December 27th, 2010*). Unless there are changes in policy, the multiplier coefficients will equal 0.66 for most oil products until 2015. The calculated rates of export taxes on crude oil and oil products can be found in *Government Decree No.695 from November 16th, 2006*.

The export tax rate on natural gas is 30%, while the export tax rate on liquefied petroleum gas (LPG) is specific and calculated according to the formula shown in Table 4.3. For example, if the price of LPG is higher than 740 \$/ton, then the specific tax rate on LPG equals 135 \$/ton plus 0.7 times the difference between the observed average price and 740 \$/ton.

**Table 4.3: Formula for the Calculation of Export Taxes on LPG**

| **Tax regimes** | **Formula** |
|---|---|
| if $PW_{gas} < 490$ \$/ton | then $TE_{LPG} = K_1*490$ |
| if 490 \$/ton $<PW_{gas} < 640$ \$/ton | then $TE_{LPG} = K_2*(PW_{gas} – 490)$ |
| if 640 \$/ton $<PW_{gas} < 740$ \$/ton | then $TE_{LPG} = 75 + K_3*(PW_{gas} – 640)$ |
| if $PW_{gas} > 740$ \$/ton | then $TE_{LPG} = 135 + K_4*(PW_{gas} – 740)$ |
| where $PW_{gas}$ is the average price of LPG observed on the border of Poland, $TE_{LPG}$ is the specific rate of export tax on LPG, $K_1 = 0$, $K_2 = 0.5$, $K_3 = 0.6$, $K_4 = 0.7$. | |

Source: Government Decree No.1155 from December 27th, 2010.

According to the theoretical literature on taxation, export taxes can be welfare improving for countries with market power in export markets. Otherwise, imposing export taxes reduces welfare and economic growth. Often export taxes are also used to generate government revenues or to encourage high value added (processing) industries. In both cases, export taxes are not the first best policy instrument to achieve the objective (Devarajan et al., 1996). For example, consumption taxes such as value added taxes or income taxes are considered as more efficient revenue rising instruments than production taxes (taxes on intermediates) (Diamond and Mirrlees, 1971). The intuition behind this is that consumption taxes distort only the consumption-leisure choice, while taxes on intermediates distort production as well as consumption decisions. High export taxes on energy in Russia seem to be a rational policy instrument since Russia is a large exporter of energy. Moreover, export taxation of energy can be justified by income equity considerations because energy resources are owned by a relative small group of rich households. Concerns are that export tax rates may be “too” high.

## 4.3 Domestic Taxes

As shown in Table 4.4, the rate of corporate income tax was 20%, the rate of value added tax was 18%, the flat tax rate on labour earnings was 13%, and the rate of social security contributions was 34% in 2012. In February, 2012, the rate of mineral tax on the extraction of crude oil was approximately 411.2 \$/ton, on condensate gas it was 18.5 \$/ton, and on natural gas it was 8 \$/1000$m_3$. The rate of excise tax on petrol (Euro-5) was approximately 227 \$/ton and for diesel (Euro-5) it was approximately 119 \$/ton in 2012.

**Table 4.4: Tax System of the Russian Federation**

| | |
|---|---|
| | **Federal taxes[17]:** |
| **Corporate income tax** | According to *Federal Law No. 223-FZ from November 26th, 2008*, the rate of corporate income tax was reduced from 24% to 20% in 2008. |
| **Value added tax** | According to *Federal Law No. 117-FZ from July 7th, 2003*, the rate of value added tax was reduced from 20% to 18% in 2003. Moreover, a tax rate of 10% is applied on some products such as food products, children's clothing, books, education, and medical services. The tax rate on exported commodities equals 0%. |
| **Personal income tax** | The flat tax rate on labour income was 13%, the tax rate on dividends was 35%, and tax rates on other personal income were 9% and 30% in 2012. |
| **Social security contributions** | According to *Federal Law No. 212-FZ from July 24th, 2009*, a unified social tax with a rate of 26% was replaced by social security contributions (SSC) with a rate of 34%. SSC are distributed between different uses: a pension fund (26%), a social insurance fund (2.9%), and obligatory health insurance (5.1%). |
| **Mineral resource extraction tax** | Mineral resources extraction taxes, *inter alia*, are imposed on condensate and natural gas, coal, and crude oil with different specific tax rates. For example, in February, 2012 the rate of mineral tax on the extraction of crude oil was approximately 411.2 $/ton, condensate gas was 18.5 $/ton, and natural gas was 8 $/1000m$_3$. For more details, see the text below. |
| **Excise tax** | Excise taxes are imposed on commodities such as alcohol, cigarettes, cars, and petroleum products with different specific tax rates. Rates of excise taxes on petroleum products differ among products according to their environmental impact. For example, in 2012, the rate of excise tax on petrol (Euro-5) was approximately 227 $/ton and for diesel (Euro-5) it was approximately 119 $/ton. For more details, see the text below. |
| **Other taxes** | Federal taxes also include (1) water taxes, (2) state fees, and (3) fees for the use of biological resources. These taxes are specific with different tax rates. |
| | **Regional and local taxes:** |
| **Transport and gambling tax** | These are specific tax rates which differ by region. |
| **Property tax** | Regions may set their own tax rates, yet tax rates may not exceed 2.2% of the property value. |
| **Land tax** | The tax rate can be either 0.3% or 1.5% of the value of the land. |

Source: Russian Tax Code (2012).

**Mineral resource extraction taxes.** Table 4.5 shows tax rates on the extraction of condensate and natural gas. The rate of mineral tax on the extraction of natural gas was approximately 8 $/1000m$_3$ in 2012, which was about 10% of the average price[18] of natural gas for households.

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[17] The differentiation between federal, regional and local taxes is in accordance with Russia's three-level budget system.

[18] Prices of natural gas for households are regulated by the Federal Tariff Service. According to the *Regulation of Federal Tariff Service No. 333-e/2 from December 9th, 2011*, the average price of natural gas for households was

The multiplier coefficient ($K_{ng}$) is planned to be reduced from 0.493 to 0.447 until 2014. In 2012 the tax rate on condensate gas was approximately 18.5 $/ton. Associated gas is not subject to taxation.

**Table 4.5: Rates of Mineral Tax on Gas Extraction from 2012 to 2014**[19]

| Time period | Condensate gas | Natural gas |
|---|---|---|
| **from January 1st to December 31st, 2012** | $TM_{cgas}$ =18.5 $[20]/ton | $TM_{natlgas}$ = $K_{ng}$*17 $/1000m3,<br>where $K_{ng}$=0.493 |
| **from January 1st to December 31st, 2013** | $TM_{cgas}$ = 19.7 $/ton | $TM_{natlgas}$ = $K_{ng}$*19 $/1000m3,<br>where $K_{ng}$=0.455 |
| **from January 1st, 2014** | $TM_{cgas}$ = 21.6 $/ton | $TM_{natlgas}$ = $K_{ng}$*21 $/1000m3,<br>where $K_{ng}$=0.447 |
| where $TM_{cgas}$ is the specific mineral tax rate on the extraction of condensate gas, $TM_{natlgas}$ is the specific mineral tax rate on the extraction of natural gas, and $K_{ng}$ are multiplier coefficients. | | |

Source: Russian Tax Code (2012).

The rate of mineral tax on the extraction of coking coal was approximately 1.9 $/ton in 2012, which equals 2.3% of the producer price[21] (82 $/ton) and the tax rate for brown coal was approximately 0.4 $/ton in 2012, which equals 2.6% of the producer price (15 $/ton).

According to the *Russian Tax Code*, the rate of mineral tax on the extraction of crude oil is calculated as follows:

$$TM_{oil} = BTM_{oil} * K_P * K_D * K_S$$

$$K_P = (PW_{oil} - 15) * \frac{ER}{261}$$

$$K_D = 3.8 - 3.5 * \frac{N}{V} \qquad \text{if } 0.8 < \frac{N}{V} < 1$$

$$K_D = 0.3 \qquad \text{if } \frac{N}{V} > 1$$

$$K_D = 1 \qquad \text{others}$$

$$K_S = 0.125 * V_S + 0.375 \qquad \text{if } V_S < 5 \text{ Mio. ton and } \frac{N}{V_S} \le 0.5$$

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approximately 86 $/1000m3 since July, 2012. The price was recalculated using an exchange rate of 30 Ruble/$. The legal document is available at the official web-side of the Federal Tariff Service, http://www.fstrf.ru/tariffs/info_tarif/gas

[19] Tax rates for 2013 and 2014 are calculated by indexing the current tax rate with the expected inflation rate.

[20] The tax rates are recalculated from Ruble into USD using an exchange rate of 30Ruble/$ with an accuracy of one decimal point.

[21] Producer prices of coal are taken from the Federal State Statistic Service, available at http://www.gks.ru/wps/wcm/connect/rosstat/rosstatsite/main/price/#

$$K_S = 1 \qquad \text{if } V_S \geq 5 \text{ Mio. ton and } \frac{N}{V_S} > 0.5$$

$$K_S = 1 \qquad \text{for the difference } (N\text{-}V_S) \text{ if } V_S > N$$

where $TM_{oil}$ is the company specific mineral tax rate on crude oil in Ruble/ton, $BTM_{oil}$ is the base mineral tax rate on crude oil in Ruble/ton, $K_P$ is a coefficient representing changes of the world price of crude oil, $K_D$ is a coefficient representing the depletion of resources, $K_S$ is a stock coefficient, $PW_{oil}$ is the average price of Urals oil in $/barrel, $ER$ is the exchange rate, $N$ is the volume of extracted oil, $V$ are oil reserves registered on January 1st, 2006, $\frac{N}{V}$ is the depletion rate with respect to $V$, $V_S$ are oil reserves registered in the previous year, and $\frac{N}{V_S}$ is the ratio of reserves. The base mineral tax rate on crude oil ($BTM_{oil}$) was approximately 14 $/ton in 2011, 15 $/ton in 2012, and 16 $/ton in 2013. Tax rates for 2012 and 2013 are calculated by indexing the current tax rate with the expected inflation rate.

**Environmental taxes**. Among energy commodities, excise taxes are applied only on oil products such as petrol and diesel as specific tax rates. According to *Federal Law No.282-FZ November 28th, 2009*, since January, 2011, rates of excise tax on oil products differ according to adverse environmental effects[22], where a high tax rate corresponds to oil products with worse environmental effects, as shown in Table 4.6. For example, from January until June, 2012 the excise tax rate on petrol (Euro-3) was approximately 246 $/ton, whereas it was 227 $/ton on petrol (Euro-5). Hence, excise taxes on oil products can be considered as taxes on pollution.

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[22] This is according to European environmental standards for fuels, which were introduced in Russian with *Government Degree No. 118 from February 27th, 2008*.

**Table 4.6: Excise Taxes on Oil Products from 2012 to 2014 (USD per ton[23])**

| | from January 1st to June 30th, 2012 | from July 1st to December 31st, 2012 | from January 1st to December 31st, 2013 | from January 1st to December 31st, 2014 |
|---|---|---|---|---|
| Petrol (others) | 258 | 274 | 337 | 370 |
| Petrol (Euro-3) | 246 | 263 | 325 | 258 |
| Petrol (Euro-4) | 227 | 227 | 285 | 314 |
| Petrol (Euro-5) | 227 | 171 | 171 | 189 |
| Diesel (others) | 137 | 143 | 195 | 215 |
| Diesel (Euro-3) | 127 | 143 | 195 | 215 |
| Diesel (Euro-4) | 119 | 119 | 164 | 181 |
| Diesel (Euro-5) | 119 | 99 | 144 | 159 |
| Motor oil | 202 | 202 | 250 | 275 |
| SRG | 261 | 261 | 321 | 353 |

**SRG** is the straight-run gasoline.

Source: Russian Tax Code (2012).

The producer price of petrol (Euro-3) was approximately 604 USD per ton in 2011, whereas the excise tax was 189 USD per ton, which accounts for 31% of the producer price (Russian Tax Code, 2010; FSSS, 2012c). Furthermore, according to *Government Decree No.632 from August 28th, 1992* as well as *Federal Law N 7-FZ from January 10th, 2002,* there are also environmental payments (Table 4.7).

**Table 4.7: Payments on Air Pollutions from Usage of Energy Inputs in 2009 (USD[24] per ton)**

| | Limit |
|---|---|
| $N_2O$ | 8.67 |
| NO | 5.83 |
| $C_4H$ | 8.33 |
| CO | 0.1 |
| $S_2O$ | 3.5 |

Source: Government Decree No.632 from August 28th.

For instance, all thermal power generation companies in Russia made some payments for local air pollution from nitrogen oxide, carbon monoxide, sulphur dioxide, particles and others. The average share of emission payments, however, does not exceed 0.1% of the total production costs (EFA, 2009a; Power Generation Company Reports, 2009).

## 4.4 Tax Interactions: Relevance of Export Taxes

The theoretical literature on environmental taxation is mainly focused on pre-existing distortionary taxes in the labour and capital markets (Goulder et al., 1997; de Mooij and

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[23] The rates of excise taxes are recalculated from Ruble into USD by using an exchange rate of 30 Ruble/USD with an accuracy of zero decimal points.

[24] Recalculated from Ruble into USD with an exchange rate equals 30 Ruble/USD.

Bovenberg, 1998), whereas interactions with other taxes such as trade taxes, valued added taxes, excise taxes, and mineral resource extraction taxes are often neglected.

Using the analytical model developed by Goulder et al. (1997), and further modified to an open economy model[25] by Parry (2001), the welfare effect of pollution taxes is analysed. Since the Russian economy strongly depends on revenues from export taxes on energy resources, the model framework is extended by introducing an export tax on polluting commodities. Household utility is given by the following equation:

$$U = u(C_1, C_2, H) - v(E_H)\,, \tag{4.4.1}$$

where $u(*)$ is a utility function which is quasi-concave and $v(*)$ is a disutility function which is concave. Both functions are continuous. $C_1$ is the domestic demand for the non-polluting good 1, which is a composite of the domestically produced good ($Q_1$) and the imported good ($M$). The domestically produced and imported good 1 are treated as perfect substitutes (equation 4.4.2). $C_2$ is the domestic demand for the polluting good 2, which is produced domestically only. The domestic supply of good 2 ($C_2$) is defined as the difference between the total supply ($Q_2$) and export ($X$), as given in equation (4.4.3). A situation is considered, where the country is an exporter of the polluting good. $H$ is leisure.

$$C_1 = Q_1 + M\,, \tag{4.4.2}$$

$$C_2 = Q_2 - X\,. \tag{4.4.3}$$

A small open economy is assumed, where the world price of the exported good ($X$) and the world price of the imported good ($M$) are normalised at unity. Therefore, the trade account balance is simply given by the following equation:

$$M = X\,, \tag{4.4.4}$$

Consumption of good 2 induces emissions. The environmental quality at home country ($E_H$) and abroad ($E_A$) is defined by the following functions:

$$E_H = e_H(C_2)\,, \tag{4.4.5}$$

$$E_A = e_A(X)\,. \tag{4.4.6}$$

The marginal environmental damage ($D$) from consumption of good 2 ($C_2$) in the home country is measured in value terms. This can be derived using the disutility function (4.4.1) and (4.4.5):

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[25] To make it comparable, we keep the notation applied by Parry (2001).

$$D=\frac{1}{\lambda}\frac{\partial v}{\partial e_H}\frac{\partial e_H}{\partial C_2}, \tag{4.4.7}$$

where $\lambda$ is the marginal utility of income. Perfect competition and constant returns to scale in the production of both goods is assumed, where labour is the only input. Therefore, supply of both goods is perfectly elastic.[26] The marginal product of labour is constant, implying a perfectly elastic demand for labour, whereas labour supply faces an upward sloping curve. Normalising the wage rate and prices at unity, the economy resource constraint can be written as follows:

$$T=Q_1+Q_2+H\ , \tag{4.4.8}$$

where *T* is the household time endowment. The total labour supply is the difference between the time endowment and leisure (*T* – *H*). Households are assumed to maximise utility (4.5.1) subject to the following household budget constraint:

$$C_1+(1+\tau_{C2})C_2=(1-\tau_L)(T-H)+TR\ , \tag{4.4.9}$$

where $\tau_{C2}$ is the pollution tax rate on good 2 ($C_2$), $\tau_L$ is the tax rate on labour income, and *TR* is the total government revenue, which is returned to households as lump-sum transfers.

The total government revenue consists of revenues from the pollution tax, labour tax, and export tax:

$$TR=\tau_{C2}C_2+\tau_L(T-H)+\tau_X X\ , \tag{4.4.10}$$

where $\tau_X$ is the export tax. *TR* is exogenous in the model because a revenue neutral experiment is analysed, where the revenue from the pollution tax is recycled through a reduction in the labour tax. Using this analytical framework, three propositions are derived.

**Proposition 1.** *The tax-interaction effect dominates the revenue-recycling effect if* $\tau_{C2}>0$, $\tau_X=0$, *and* $C_1$ *and* $C_2$ *are equal substitutes for leisure.*

**Proof.** Totally differentiating equation (4.4.1) with respect to $\tau_{C2}$, the following expression for the welfare effect is obtained:

$$\frac{dU}{d\tau_{C2}}=\left(\frac{\partial U}{\partial C_2}-\frac{\partial v}{\partial e_H}\frac{\partial e_H}{\partial C_2}\right)\frac{dC_2}{d\tau_{C2}}+\frac{\partial U}{\partial C_1}\frac{dC_1}{d\tau_{C2}}+\frac{\partial U}{\partial H}\frac{dH}{d\tau_{C2}}\,. \tag{4.4.11}$$

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[26] The assumption of perfectly elastic supply of goods is a “standard” assumption which is also used in previous studies (e.g. Parry and Bento, 2000).

Maximising the utility function (4.4.1) with respect to the household income balance (4.4.9), the following first-order conditions are obtained:

$$\frac{\partial U}{\partial C_1} = \lambda\,; \qquad \frac{\partial U}{\partial C_2} = \lambda(1+\tau_{C2})\,; \qquad \frac{\partial U}{\partial H} = \lambda(1-\tau_L)\,. \tag{4.4.12}$$

Implicit demand functions are the following:

$$C_1(\tau_{C2},\tau_L)\,; \qquad C_2(\tau_{C2},\tau_L)\,; \qquad H(\tau_{C2},\tau_L)\,. \tag{4.4.13}$$

Substituting (4.4.2) and (4.4.7) into (4.4.11), we obtain:

$$\frac{1}{\lambda}\frac{dU}{d\tau_{C2}} = \left(1+\tau_{C2}-D\right)\frac{dC_2}{d\tau_{C2}} + \frac{dC_1}{d\tau_{C2}} + (1-\tau_L)\frac{dH}{d\tau_{C2}}\,. \tag{4.4.14}$$

Differentiating (4.4.8) with respect to $\tau_{C2}$ and making use of (4.4.2), (4.4.3), and (4.4.4), we obtain:

$$\frac{dC_2}{d\tau_{C2}} = -\frac{dC_2}{d\tau_{C2}} - \frac{dH}{d\tau_{C2}}\,. \tag{4.4.15}$$

Substituting (4.4.15) into (4.4.14), we obtain:

$$\frac{1}{\lambda}\frac{dU}{d\tau_{C2}} = \left(\tau_{C2}-D\right)\frac{dC_2}{d\tau_{C2}} - \tau_L\frac{dH}{d\tau_{C2}}\,. \tag{4.4.16}$$

Totally differentiating the implicit demand function for leisure (4.4.13) with respect to $\tau_{C2}$, we obtain:

$$\frac{dH}{d\tau_{C2}} = \frac{\partial H}{\partial \tau_{C2}} + \frac{\partial H}{\partial \tau_L}\frac{d\tau_L}{d\tau_{C2}}\,. \tag{4.4.17}$$

Totally differentiating the government revenue equation (4.4.10) with respect to $\tau_{C2}$, after some simple algebraic manipulation, gives:

$$\frac{d\tau_L}{d\tau_{C2}} = -\frac{C_2 + \tau_{C2}\dfrac{dC_2}{d\tau_{C2}} - \tau_L\dfrac{\partial H}{\partial \tau_{C2}} + \tau_X\dfrac{dX}{d\tau_{C2}}}{T - H - \tau_L\dfrac{\partial H}{\partial \tau_L}}\,. \tag{4.4.18}$$

Substituting (4.4.18) and (4.4.17) into (4.4.16), we can obtain:

$$\frac{1}{\lambda}\frac{dU}{d\tau_{C2}} = \underbrace{\left(\tau_{C2} - D\right)\frac{dC_2}{d\tau_{C2}}}_{dW^P} + M\left(\underbrace{C_2 + \tau_{C2}\frac{dC_2}{d\tau_{C2}} + \tau_X \frac{dX}{d\tau_{C2}}}_{\partial W^R}\right) - \underbrace{(1+M)\tau_L \frac{\partial H}{\partial \tau_{C2}}}_{\partial W^I} \text{ , (4.4.19)}$$

where $M = \dfrac{\tau_L \dfrac{\partial H}{\partial \tau_L}}{T - H - \tau_L \dfrac{\partial H}{\partial \tau_L}}$. (4.4.20)

According to Goulder et al. (1997), the numerator in equation (4.4.20) defines the partial equilibrium net welfare from a marginal change in the labour tax. This is the change in leisure multiplied by $\tau_L$. The denominator defines the partial equilibrium change in government revenues from a marginal change in the labour tax. Therefore, *M* are the partial equilibrium efficiency costs[27] resulting from an increase in the labour tax to receive an additional dollar. The first term in the RHS of the equation (4.4.19) is the Pigouvian effect, $dW^P$, which is defined as a reduction of $C_2$, multiplied by the difference between the marginal social benefit and the marginal social cost. The revenue recycling effect is $\partial W^R$. The revenue-recycling effect defines efficiency gains from a reduction of the labour tax as well as gains from pollution tax revenues. The tax interaction effect is $\partial W^I$. This is defined as the welfare loss, resulting from decreases in the labour supply and in revenues from labour taxes. The tax interaction effect ($\partial W^I$) can be shown by the following approximation, which is derived following Goulder et al. (1997) (see Appendix A):

$$\partial W^I = \phi_C M C_2 , \qquad (4.4.21)$$

where $\phi_C = \dfrac{n_{C_2H}{}^C + n_{LI}}{n_{C_1H}{}^C \dfrac{C_1}{C_1 + C_2} + n_{C_2H}{}^C \dfrac{C_2}{C_1 + C_2} + n_{LI}}$,

where $n_{C_1H}{}^C$ and $n_{C_2H}{}^C$ are the compensated elasticities of demand for $C_1$, and $C_2$ with respect to the price of leisure and $n_{LI}$ is the income elasticity of labour supply. The degree of substitution between $C_2$ and leisure compared to that between total consumption and leisure is measured by $\phi_C$. For example, if $C_1$ and $C_2$ have equal elasticities of substitution for leisure ($n_{C_1H}{}^C$ equals $n_{C_2H}{}^C$), then $\phi_X$ equals unity. Therefore, the difference between the revenue-recycling effect ($\partial W^R$) and the tax-interaction effect ($\partial W^I$) equals:

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[27] According to Goulder et al. (1997), *M* is also defined as the marginal excess burden of labour taxation, where one plus the marginal excess burden of taxation equals the marginal cost of public funds.

$$M\left(\tau_{C2}\frac{dC_2}{d\tau_{C2}}+\tau_X\frac{dX}{d\tau_{C2}}\right). \qquad (4.4.22)$$

If $\tau_{C2} > 0$ and $\tau_X = 0$, then $\partial W^I > \partial W^R$ by the term $M\left(\tau_{C2}\frac{dC_2}{d\tau_{C2}}\right)$. **Q.E.D.**

This confirms the conclusion drawn by Parry (1995) and Goulder et al. (1997) and implies a failure of the strong double dividend hypothesis. The intuitive explanation behind this is that narrow-based taxes (pollution taxes) induce a larger marginal excess burden compared to broad-based taxes (income taxes). This is because substituting narrow-based taxes for broad-based taxes raise a wide range of substitution possibilities (Parry and Oates, 2000). Nevertheless, if pollution goods and leisure are complements, the tax-interaction effect is an efficiency gain (Goulder et al., 1997).

**Proposition 2.** *The tax-interaction effect is less than the revenue-recycling effect if* $0 < \tau_{C2} < \tau_X$ *and* $C_1$ *and* $C_2$ *are equal substitutes for leisure.*

**Proof.** Under the assumption of a small open economy and homogeneity of $C_2$ and $X$ in supply, $\frac{dC_2}{d\tau_{C2}} = \frac{dX}{d\tau_{C2}}$ where $\frac{dC_2}{d\tau_{C2}} < 0$ and $\frac{dX}{d\tau_{C2}} > 0$. Therefore, from equation (4.4.22), if $\tau_{C2} < \tau_X$, then $\partial W^I < \partial W^R$. **Q.E.D.**

Expanding the base of the export tax results in additional revenues, which allows for a larger reduction in labour taxes. Such a *positive tax-interaction effect* decreases the cost of environmental tax reform, raising the possibility of a strong double dividend. Due to export taxes, the polluting good is oversupplied domestically and undersupplied in the export market. Therefore, introducing a pollution tax has a corrective effect since this leads to a reduction in the demand for the polluting goods, whereas its export supply increases.

**Proposition 3.** *The tax-interaction effect equals the revenue-recycling effect if* $\tau_{C2} = \tau_X$, $\tau_X > 0$, *and* $C_1$ *and* $C_2$ *are equal substitutes for leisure.*

**Proof.** This proof follows from the proof of **Proposition 2** (see equation 4.4.22). **Q.E.D.**

Using this analytical framework, we can also see that introducing (increasing) pollution taxes harms the environmental quality abroad: $\frac{de_A}{d\tau_{C2}} = \frac{\partial e_A}{\partial X}\frac{dX}{d\tau_{C2}} < 0$ because $\frac{\partial e_A}{\partial X} < 0$ and $\frac{dX}{d\tau_{C2}} > 0$. This indicates increases in emissions abroad.

## 4.5 Summary of the Chapter

The theoretical literature on the double dividend concept is mainly focused on interactions of environmental taxes with pre-existing labour and capital taxes, while tax interactions with other taxes are often neglected. In particular, export taxes on crude oil, petroleum products and gas are a substantial source of government revenues in Russia: approximately 21% of total government revenues. Export taxation leads to oversupply of energy in domestic markets since it lowers the domestic price level of energy. Introducing environmental taxes in Russia would increase revenues from export taxes via higher export supplies of energy. At the same time, high revenues from export taxes reduce the cost of environmental tax reform since they allow for a larger reduction in distortionary taxes. The relevance of the interaction between carbon taxes and export taxes on energy as well as other taxes are further analysed in the empirical analysis in Section 7.

# 5 Energy Markets

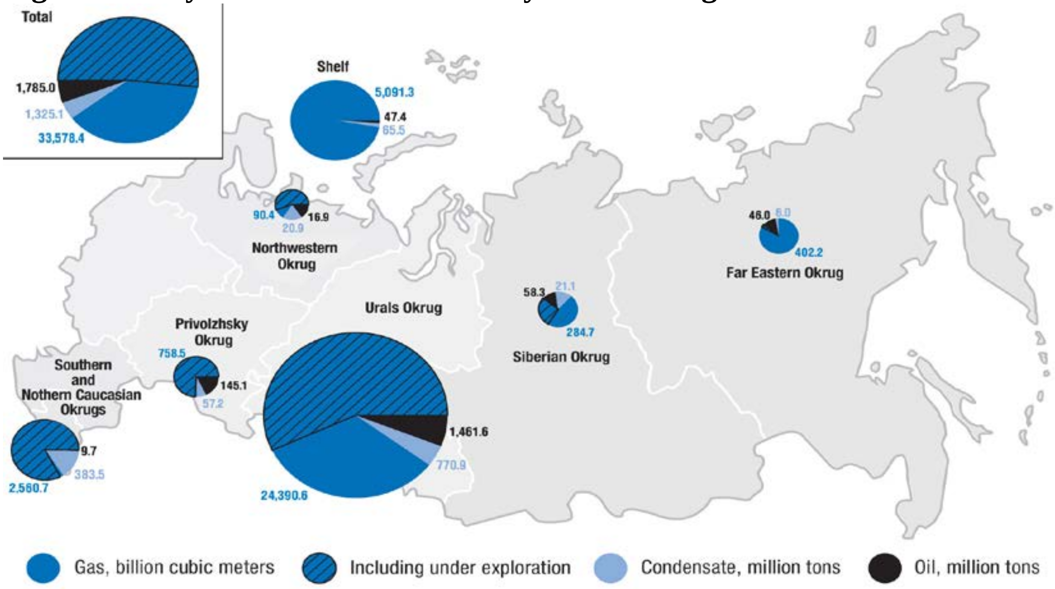
As discussed in Chapter 3, the occurrence of a strong double dividend is ambiguous since this depends on various factors and assumptions. Analytical models due to their simplicity are not able to capture all real-world complexities. A general equilibrium framework turns out to be an appropriate tool to deal with this issue because this allows analysing the effects of environmental taxation in the presence of pre-existing distortions as well as this provides an explicit interaction between output and factor markets. From Chapter 5, this study departs from the theoretical to a numerical analysis. The design of energy markets determines the response of demand and supply of energy to a policy simulation. Hence, an explicit design of the model with respect to energy markets is expected to be crucial for the credibility of results. Chapter 5 provides an overview of energy markets in Russia. Four energy markets – gas market, oil market, coal market and electricity market – are analysed with respect to the market structure. This chapter forms the basis for the model design described further in Chapter 6.

## 5.1 Gas Market

### 5.1.1 Supply

Russia has the largest natural gas reserves in the world (British Petroleum, 2010). Moreover, Russia is the world’s largest producer and exporter of dry natural gas (EIA, 2011c). As shown in Figure 5.1, Ural region is the major producer of natural gas. This region has also the largest reserves of natural gas in Russia. Following Stern (2009), the main supply sources and demand categories of the Russian gas market are defined. There are three main sources of gas supply in Russia: Gazprom production, non-Gazprom production and imports from Central Asia.

**Figure 5.1: Hydrocarbons Produced by Russian Regions in 2008**



Source: Gazprom (2011a).

The largest domestic producer of natural gas is Gazprom, whose share accounted for 83% of Russian total gas production in 2008. Gazprom is a state run company with a government property share of slightly above 50%. Gazprom operates as a vertically integrated company, which deals with production, distribution and transportation of natural gas (Ministry of Energy, 2011a). Gazprom is a proprietary organisation in Russia’s unified system of gas transportation. Therefore, Gazprom has control over all domestic and export transportation of gas from Russia (Gazprom, 2011b). The unified gas supply system in Russia is a natural monopoly. According to *Government Decree No.1021 from December 29th, 2000*, to avoid a monopolistic behaviour of Gazprom with respect to independent gas producers, transport tariffs for natural gas are regulated by the government. Gazprom, however, is entitled to decide about the volume of gas transitions from other companies so that independent gas producers do not have free access to pipeline networks. Based on the demand for gas and the pipeline capacity, Gazprom provides several quotas of gas transportation for independent gas producers (Gazprom, 2011c). A non-discriminating access to pipeline networks for independent gas producers remains a controversial issue in Russian gas policy. In addition, Gazprom owns many holdings in such sectors as banking, insurance, agriculture, mass media and construction, which enforces Gazprom’s political power (Ahrend and Tompson, 2005).

Nevertheless, Gazprom does not have the absolute control over production of natural gas in Russia. The role of independent gas producers has increased recently. The production share of independent companies accounted for 17% of Russian total gas production in 2008, whereas in 2003 it was approximately 12% (Gazprom, 2010). Non-Gazprom natural gas is produced either by oil companies as a by-product of oil production or by small gas companies (Robeck, 2006). The largest independent producers of gas in Russia are the companies “Itera”, “Novatek”, and “TNK-WP Holding” (Gazprom, 2011d).

### 5.1.2 Demand

Three main gas markets are distinguished: (1) domestic market, (2) European market, and (3) Commonwealth of Independent States (CIS’s) market. Russia is not only a large producer of gas, yet it is also a large consumer of gas. The domestic market is the largest market, whose share accounted for 58% of total gas supply in 2008 (Table 5.1).

**Table 5.1: Supply of Natural Gas to Domestic and Export Markets**

| | | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|---|
| **Supply to domestic markets** | BCM* | 327.0 | 333.5 | 339.8 | 352.0 | 356.4 | 352.8 |
| | share to total, % | 58.3 | 57.6 | 57.5 | 58.0 | 59.0 | 58.4 |
| | growth rate, % | 0.0 | 1.99 | 1.89 | 3.59 | 1.25 | -1.01 |
| incl. imports from Central Asia | BCM | 0.0 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 |
| **Supply to export markets** | BCM | 233.8 | 245.9 | 251.2 | 254.7 | 247.3 | 251.1 |
| | share to total, % | 41.7 | 42.4 | 42.5 | 42.0 | 41.0 | 41.6 |
| | growth rate, % | 0.0 | 5.18 | 2.16 | 1.39 | -2.91 | 1.54 |
| incl. transits from Central Asia to exports | BCM | 47.0 | 50.3 | 54.5 | 56.8 | 59.7 | 61.3 |
| **Total supply** | BCM | 560.8 | 579.4 | 591.0 | 606.7 | 603.7 | 603.9 |
| | growth rate, % | 0.0 | 7.02 | 8.35 | 4.22 | 5.11 | 2.68 |

* Billion cubic meters

Source: Gazprom (2010).

**Domestic market.** The domestic market of natural gas is divided into a regulated and a non-regulated market. Gazprom and its subsidiaries operate in the regulated market, where domestic prices of gas are administratively regulated by the Federal Tariff Service (FTS) (Government Decree No.1205 from December 31st, 2010). Independent producers of natural gas operate in the non-regulated market. Due to administrative price regulation, domestic prices of gas were approximately at 50% of export prices in 2010 (Ministry of Economics, 2010). Moreover, regulated prices of natural gas differ by household group as well as industry and region (FTS, 2010).

The Russian economy depends strongly on natural gas. Natural gas is the main energy input in total energy consumption. For example, the share of gas accounted for 54% of total energy consumption in 2009, followed by crude oil and oil products (21%), coal (14%), nuclear (6%), and hydroelectricity (6%) (British Petroleum, 2010). As shown in Table 5.2, the largest domestic consumer of natural gas in 2008 was the power generation sector with a share of 33% of total domestic demand for gas, followed by households (17%), and the utility sector (11%). The largest consumers of gas among Russian regions are Central and Volga regions, whose consumption share accounted for 66% of total domestic consumption of gas. This is because industries are mainly concentrated in the European part of Russia (Gazprom, 2011e).

**Table 5.2: Demand for Natural Gas from Gazprom by Consumer Type (per cent)**

| | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** |
|---|---|---|---|---|---|---|
| Power generation | 37 | 37 | 38 | 37 | 37 | 33 |
| Metallurgy | 6 | 7 | 7 | 6 | 7 | 7 |
| Agrochemical industry | 6 | 6 | 7 | 6 | 7 | 7 |
| Households | 16 | 15 | 16 | 15 | 16 | 17 |
| Utility sector | 11 | 9 | 10 | 10 | 11 | 11 |
| Rest | 24 | 26 | 22 | 26 | 24 | 27 |
| **Total** | 100 | 100 | 100 | 100 | 100 | 100 |

Source: Gazprom (2010).

**Export market.** Russia is the world's largest exporter of natural gas: for example, its production share was 20% of world's total natural gas production in 2009 (British Petroleum, 2010). Among Russian gas producers, only Gazprom is entitled to export natural gas (Federal Law No.117 from July 18th, 2006) so that Gazprom has a legal monopoly with respect to exports of natural gas from Russia. Gazprom exports natural gas to 32 countries such as CIS, EU as well as Turkey, Japan and other Asian countries (Ministry of Energy, 2011a). As shown in Table 5.3, the largest importers of Russian natural gas are Ukraine and Germany. The consumption share of Russian gas in most European markets is high. Therefore, Russia can have some market power in these markets. For example, consumption of natural gas in countries, such as Slovakia, Finland, Macedonia, and Belarus consists mainly of gas deliveries from Russia. According to the estimation carried out by Tarr and Thomson (2004), the Lerner index for Russian gas in European markets varies from 0.37 to 0.63, which indicates significant market power. In contrast, Locatelli (2008) argues that the possibility to exercise market power by Gazprom in export markets is limited because of long-term contracts and limited capacity.

**Table 5.3: Major European and CIS's Importers of Russian Natural Gas in 2010**

| | **Export supply (bn. m$^3$)** | **Export shares [a] (per cent)** | **Import shares [b] (per cent)** |
|---|---|---|---|
| **European importers:** | | | |
| Austria | 5.4 | 2.4 | 68 |
| Belgium | 3.3 | 1.5 | n.a. |
| Finland | 4.4 | 2.0 | 100 |
| France | 10.0 | 4.5 | 23 |
| Germany | 33.5 | 15.2 | 35 |
| Greece | 2.1 | 1.0 | 80 |
| Italy | 19.1 | 8.7 | 31 |
| Switzerland | 0.3 | 0.1 | 10 |
| Netherlands | 5.1 | 2.3 | 25 |
| Turkey | 20 | 9.1 | 63 |
| UK | 9.7 | 4.4 | n.a. |
| Bosnia and Herzegovina | 0.2 | 0.1 | 100 |
| Bulgaria | 2.2 | 1.0 | 100 |
| Croatia | 1.1 | 0.5 | 90 |
| Czech Republic | 7.1 | 3.2 | 68 |
| Hungary | 7.6 | 3.4 | 89 |
| Macedonia | 0.1 | 0.0 | 100 |
| Poland | 9.0 | 4.1 | 78 |
| Romania | 2.5 | 11.0 | 100 |
| Serbia | 1.7 | 0.8 | 100 |
| Slovakia | 5.4 | 2.4 | 100 |
| Slovenia | 0.5 | 0.2 | 57 |
| Rest | 2.5 | 1.1 | n.a. |
| **CIS's importers:** | | | |
| Armenia | 1.7 | 0.8 | 100 |
| Belarus | 17.6 | 8.0 | 100 |
| Estonia | 0.8 | 0.4 | 100 |
| Georgia | 0.1 | 0.0 | 13 |
| Kazakhstan | 3.1 | 1.4 | 37 |
| Latvia | 1.1 | 0.5 | 100 |
| Lithuania | 2.5 | 1.1 | 100 |
| Moldova | 3.0 | 1.4 | 57 |
| Ukraine | 37.8 | 17.1 | 100 |
| **Total** | **67.7** | **100** | **n.a.** |

[a] Export shares of gas from Russia to destination in Russian total export supply.

[b] Import shares of Russian gas in total import demand for gas in destination country.

Source: Gazprom (2010) and British Petroleum (2010).

Recently, there are some concerns about the stability of future exports of natural gas from Russia, especially Gazprom's ability to fulfil its contracts with respect to gas its supplies (IEA, 2006). The Russian gas sector has large reserves of natural gas, yet it suffers from a lack of investment in extraction and infrastructure (Goldthau, 2008; Fernandez, 2009). For instance, Soederbergh et al. (2010) show that the major Russian gas fields are in decline. Moreover, the authors stress the importance of development of large-scale projects, such as the Yamal Peninsula and Shtokman fields, which would be needed to avoid a reduction in gas supply in the near future. According to another study carried out by Fernandez (2009), export supply of gas from Russia will continue to increase but rather moderately. The growth of export supply would significantly depend, *inter alia*, on investment strategies and domestic demand for gas. Development of domestic demand for gas in Russia would be influenced by factors, such as substitution possibilities among energy inputs, changes in the economic structure, and modernization of existing capacity (Fernandez, 2009). In contrast, Stern (2005) gives a more optimistic opinion with respect to the future gas supply from Russia. He points out that the Russian gas sector faces different supply options to meet increasing domestic and export demand in the future. According to Stern (2005), development of large-scale projects such as Yamal Peninsula would satisfy domestic as well as export demand for natural gas for a long-term. Such investment projects, however, require high investments associated with high risks and uncertainties regarding future prices and demand for gas. Alternative sources of gas supply could be some small-scale projects which are less costly compared to the Yamal Peninsula project. Stern also stresses that a delay of large-scale projects would increase the importance of independent gas producers as well as imports from Central Asia. Therefore, the development of prices and demand for gas becomes one of the important factors, which would determine the Russian gas balance in the future (Stern, 2005).

### 5.1.3 Challenges for Gas Policy

According to the *Russian Energy Strategy up to 2030* (Ministry of Energy, 2009) and the *General Plan of Development of the Gas Sector* (Energyland, 2010), the main challenges of the gas sector are summarized as follows:

1) Technical and technological modernization of the gas sector, especially the pipeline network since the majority of pipelines is outdated. Deterioration of the pipeline network leads to large losses by gas transportation (Mitrova et al., 2009; Dergunova, 2007).

2) Investment in development of new gas deposits since the main gas basins in Russia are in decline.

3) Liberalization of the domestic gas market. Domestic prices of gas are still administratively regulated, and they are significantly lower than export prices.

4) Support of competition in the domestic gas market as well as non-discriminatory access to the pipeline network for non-Gazprom gas producers.

5) Development of the gas chemical and gas processing industries: for example, development of production and export of liquefied petroleum gas.

6) Diversification of export deliveries of gas because of high transit risk (conflict with Ukraine).

**Price regulation.** One of the most important issues of Russian gas policy still is the regulation of domestic prices. The Russian government planned to unify domestic and export prices of gas until 2011 based on the principle of "equal profitability" of export and domestic markets. According to this policy reform, the domestic price level should equal the average export price excluding export tax of 30% and transport costs (Government Decree No.333 from May 27th, 2007). Unified pricing for gas should lead to more efficient use of gas and encourage investment in domestic infrastructure of the sector. Another argument for unified pricing is to diversify the energy balance, by supporting the production of coal through increasing domestic prices of gas (Ministry of Economics, 2010). The Russian government has implemented a gradual increase of domestic prices of gas for industries and households. The full equalization of domestic and export prices was delayed to 2015 because of the economic crisis (Gazprom, 2011e; Government Decree No.1205 from December 31st, 2010). The unified pricing implies an increase in domestic prices of gas, which results in various effects. On one hand, increasing domestic prices of natural gas will encourage investment into extraction and infrastructure of the gas sector and provide other energy-saving measures which will lead to energy efficiency improvement (Goldthau, 2008). One of the most important factors in the analysis of Russian gas policy is how domestic demand would respond to higher gas prices, in particular sectors with a large energy saving potential (Stern, 2005; Pirani, 2009). Moreover, higher domestic prices of gas would raise the profitability of independent producers of gas in Russia. Because of low domestic prices of gas, most oil companies flare associated gas rather to sale this (Goldthau, 2008). On the other hand, unified pricing for natural gas can result in negative social and economic consequences for Russia because of higher energy costs. Tarr and Thomson (2004) found that unified pricing for gas would not be economically rationale from a Russian perspective since Gazprom has some market power in the export market. Moreover, unified pricing of natural gas will lead to increases in domestic demand for other energy fuels such as coal which produce more emissions. Therefore, dual pricing for gas can also be justified from an environmental point of view, since low domestic prices of gas imply significant environmental benefits (Dudek et al., 2006). Finally, an increase in the domestic price level of gas in Russia can lower the incentive to export some additional amount of gas apart from existing contracts. Thus, the European security of gas supply from Russia may even be worse off under unified pricing of gas (Spanjer, 2007; Sagen and Tsygankova, 2008).

**Sectoral structure.** The structure of the gas sector remains a controversial issue in Russia. The total control of Gazprom over pipeline networks and export supply of natural gas is highly criticized. At the end of the nineties, a reorganization of Gazprom into a production and transportation company was discussed. This was aimed to support non-discriminating access to pipeline networks. Currently, Gazprom is considered as an important strategical company, which reorganization is politically undesirable (Orttung et al., 2008). On the one hand, a reorganization of Gazprom would increase the competition in the Russian gas market. Moreover, free access to the pipeline system would raise incentives to invest into production and infrastructure of gas for independent producers (Grigoryev, 2007). On the other hand, a splitting up of Gazprom can deteriorate the Russian position in the export market. According to Tsygankova (2010), the relation of Gazprom’s shares in the domestic and export markets determine welfare effects of Gazprom’s reorganization. For example, a small market share in the export market and a large market share in the domestic market can lead to welfare gains from Gazprom’s reorganization. Another argument against the reorganization of Gazprom, which is often raised by Gazprom, is losses in economies of scale (Pirani, 2009). Nevertheless, it is not clear how significant benefits from economies of scale are, and whether they can overweigh welfare gains from a more competitive structure of the gas market.

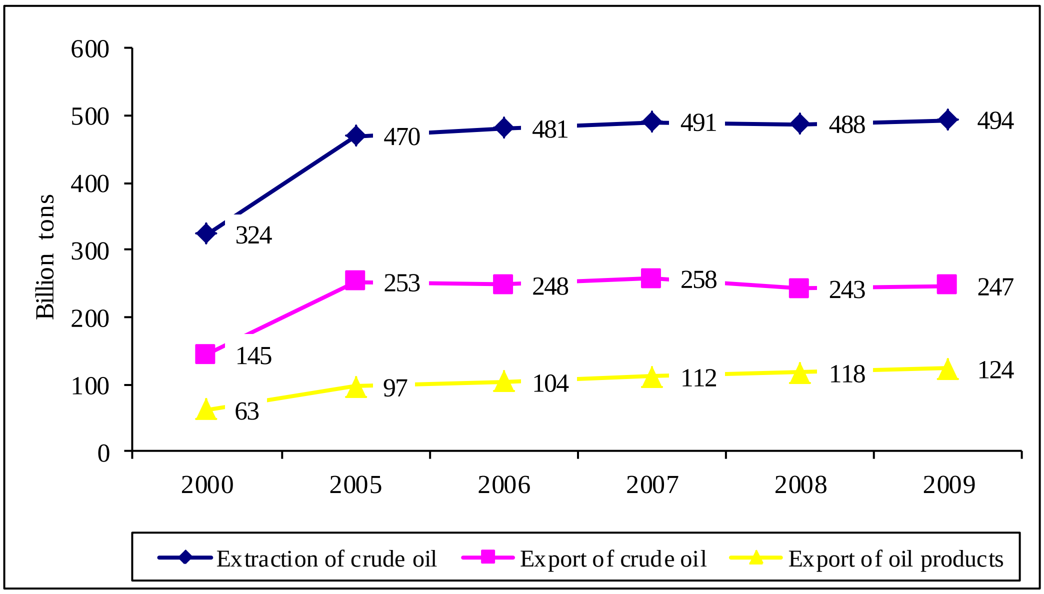
## 5.2 Crude Oil and Oil Products Market

### 5.2.1 Supply

Russia is the second largest producer of oil after Saudi Arabia. Moreover, Russia has the world’s eighth largest proved reserves of oil: approximately 13% of world’s proved reserves (Ministry of Energy, 2011c). Most Russian oil reserves are located in West Siberia, between the Ural Mountains and the Central Siberian plateau. There are also some reserves in Eastern Siberia (EIA, 2011c). The market share of petroleum products from Russia accounted for 8.6% in total world exports in 2007 (EIA, 2011a).

The oil sector in Russia consists of 10 large vertically integrated oil companies, which deal with extraction, processing and transportation of crude oil and oil products. The largest oil companies are “Rosnefty”, “Lukoil”, “TNK-BP”, “Surgutneftegas”, and “Gazprom nefty” (Ministry of Energy, 2011c). The pipeline network is a natural monopoly so that transportation of oil and oil products in Russia is controlled by state run companies "Transnefty" and "Transneftyproduct", respectively (Transnefty, 2010; Ministry of Energy, 2011c). These companies are also entitled to export crude oil and oil products. As shown in Figure 5.2, the production of crude oil has increased by 52% between 2000 and 2009.

**Figure 5.2: Extraction and Export of Oil and Oil Products (billion tons)**



Source: FSSS (2010).

### 5.2.2 Demand

**Export market.** Russia exports crude oil as well as oil products. For example, the share of exported crude oil amounted to 50% in 2009, as shown in Figure 5.2. The largest export market is the European market with a share of 81% of total export of crude oil, especially Germany and the Netherlands are the largest importers of Russian crude oil. About 12% of Russian oil exports go to Asia, whereas exports to North and South America amount to 6%, Africa (0.7%), and Australia and New Zealand (0.3%) (EIA, 2011c).

**Domestic market.** About half of extracted oil in Russia is processed into oil products such as petrol and diesel, which are sold either in domestic or export markets. Domestic prices of oil products are not regulated, but lower than export prices due to high export taxes (see Section 4.3). Furthermore, domestic prices of oil products are subject to regular inspections, which are performed by the Russian Federal Antimonopoly Service. This is because of suspicion of oligopolistic behaviour among oil companies and "too" high domestic prices of petroleum products (FAS, 2009). The largest domestic users of petroleum products are households and the transport sector.

### 5.2.3 Challenges for Petroleum Policy

According to the *Russian Energy Strategy up to 2030* (Ministry of Energy, 2009), the main challenges of the Russian oil sector are summarized as follows:

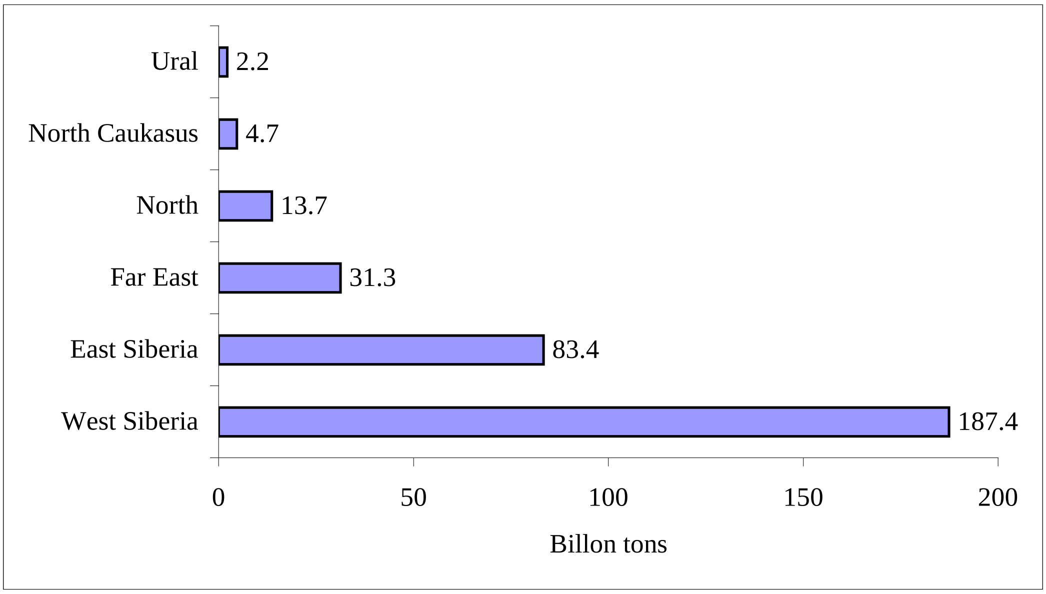
1) Technical and technological modernization of the oil sector, especially pipeline networks.
2) Development of oil refinery in Russia, i.e., development of downstream industries with high value added. As mentioned, about 50% of extracted crude oil is exported.
3) Improvement of the quality of oil products, especially with respect to their environmental impact.
4) Diversification of oil products assortment.
5) Support of competition in the domestic market of oil products since the Russian oil sector is oligopolized by some vertically integrated companies.

## 5.3 Coal Market

### 5.3.1 Supply

Russia has the second largest reserve of coal after USA (EIA, 2011c). The main regions of coal extraction are West and East Siberia, which produce about 85% of total coal production in Russia (Figure 5.3). At present, the Russian coal industry can be characterized as a liberalized and deregulated sector.

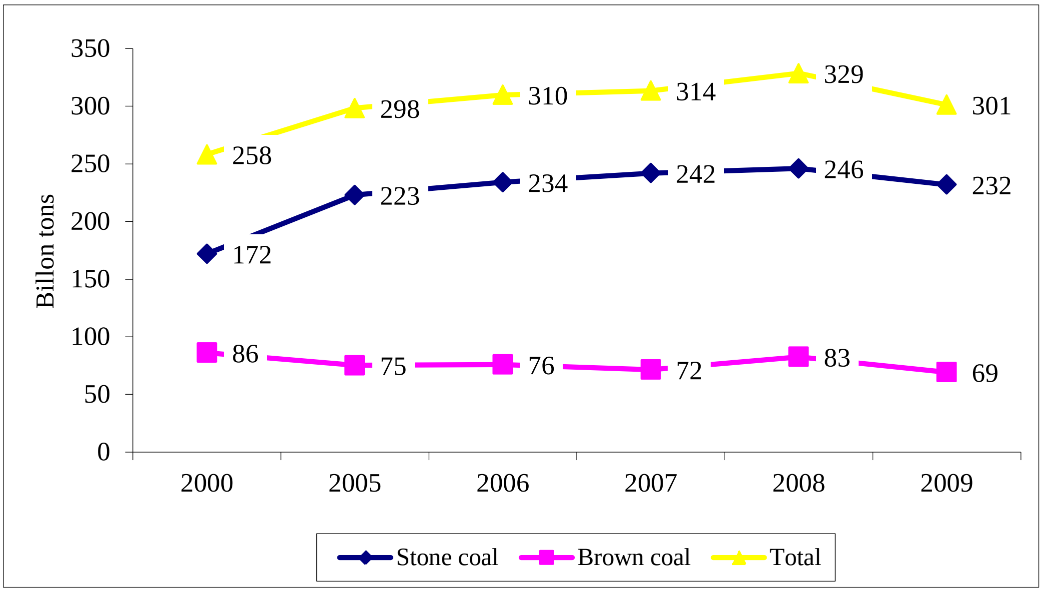
**Figure 5.3: Production of Coal by Region in 2010 (billon tons)**



Source: Ministry of Energy (2011d).

As shown in Figure 5.4, total production of coal in Russia increased by about 27% in 2010 compared to 2000. Moreover, the share of stone coal in total coal production increased compared to brown coal. For instance, the share of stone coal was 67% in 2000, whereas it increased to 77% in 2009 so that the share of brown coal was 23% in 2009. The Russian coal sector is mainly represented by ten private companies, which are formed as joint stock companies (Ministry of Energy, 2011d).

**Figure 5.4: Production of Coal Products from 2000 to 2009 (billon tons)**

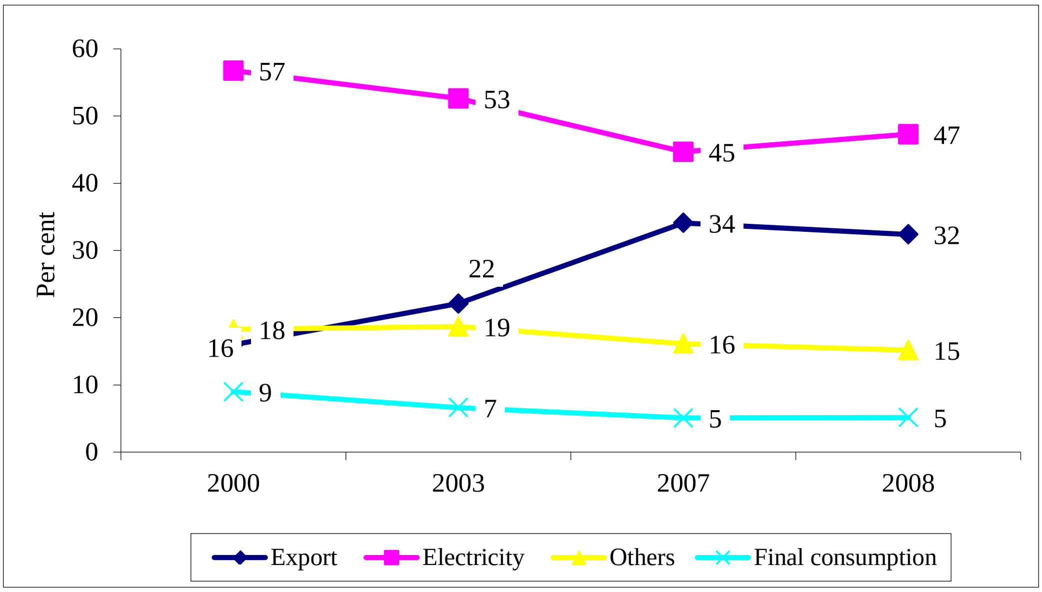


Source: FSSS (2010).

### 5.3.2 Demand

**Domestic market.** Domestic production of coal is redistributed between domestic and export markets. The domestic market is the largest market, whose share accounted for 65% of total production in 2009. Moreover, Russia imports coal as well, where almost all imports come from CIS countries in particular from Kazakhstan (Ministry of Energy, 2011d). As shown in Figure 5.5, the largest domestic consumer of coal is the electricity sector, whose share accounted for 47% of total coal production in 2008. The second largest consumer of coal is the top stream industry, which dealt with processing of coal in other energy commodities. Its share amounted to 15% in 2008. Figure 5.8 illustrates that during the period from 2000 to 2008 production of coal switched from domestic to export markets. For example, the share of exported coal in total coal production increased from 16% to 32%.

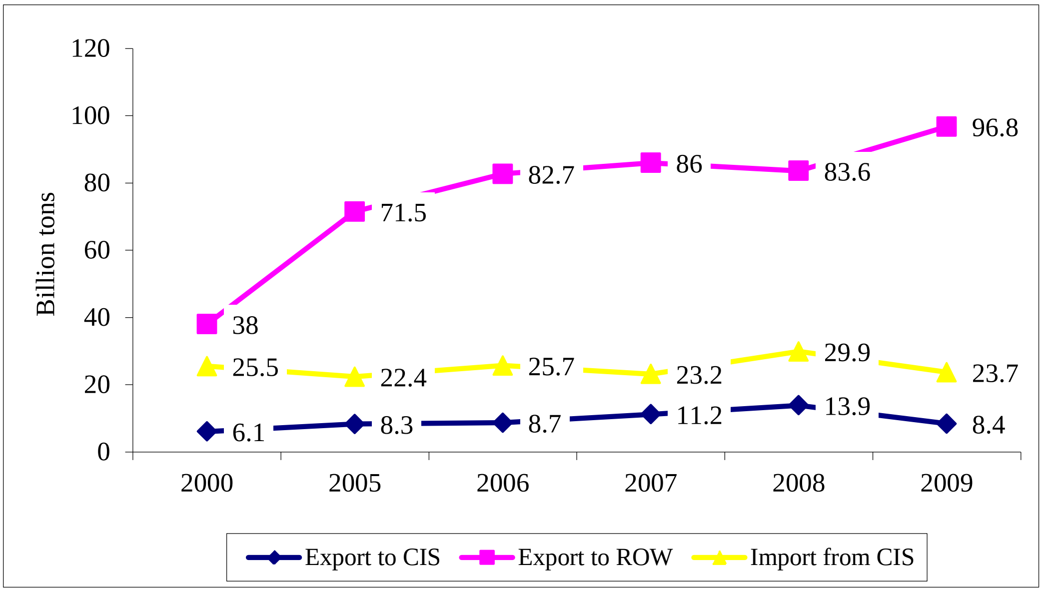
**Figure 5.5: Consumption of Coal by Demand Categories (per cent of total production)**



Source: FSSS (2010).

**Export market.** The export market can be divided into two markets: (1) CIS and (2) other export markets. The largest importers of Russian coal are Ukraine, Britain, Turkey, China, Japan, Holland, Poland and Korea, whose overall share accounts for approximately 70% of total coal exports from Russia (Ministry of Energy, 2011d). Russia exports mainly stone coal. Figure 5.6 illustrates that exports of stone coal have significantly increased in particular to non-CIS countries. For instance, total export supply of stone coal increased by 140% from 2000 to 2009.

**Figure 5.6: Export and Import of Stone Coal from 2000 to 2009 (billion tons)**



Source: FSSS (2010).

### 5.3.3 Challenges for Coal Policy

According to the *Russian Energy Strategy up to 2030* (Ministry of energy, 2009), the main challenges of the Russian coal sector are summarized as follows:

1) Technical and technological modernization of the coal sector. The coal industry suffers from a lack of investment. Low domestic prices of gas make investment in the coal industry less profitable than in the gas industry. Therefore, gas policy in Russia significantly affects the coal sector.
2) Improvement of the quality of coal products. Russian coal products are of low quality with high ash content, which varies from 20% to 40%. For example, coal for power generation is not cleaned (Kozuchowski, 2008).
3) Development of transport infrastructure.
4) Improvement of social and working standards to reduce accident and injury rates in coal mining.
5) Efficient regulation of transport tariffs for coal transportation. Transport costs accounts for a large part relative to total production costs. For example, transport costs account for 50-60% of export prices so that high transportation costs make Russian coal less competitive in the export market (Plakitkin and Plakitkina, 2009).

## 5.4 Electricity Market

### 5.4.1 Supply

The major sources of electricity generation in Russia are thermal, hydro and nuclear energy. Table 5.4 shows that the structure of electricity generation in Russia remained unchanged during the period from 2000 to 2009. Thermal energy is the main source of energy generation, whose share accounts for 66% of total electricity generation.

**Table 5.4: Structure of Electricity Generation and the Production Growth Rate (per cent)**

| Years | Nuclear | Hydro | Thermal | Growth, in per cent to 2000 |
|---|---|---|---|---|
| 2000 | 14.8 | 19.6 | 65.6 | 0.0 |
| 2001 | 15.0 | 20.5 | 64.5 | 1.1 |
| 2002 | 15.9 | 19.1 | 65.0 | 1.6 |
| 2003 | 16.3 | 17.8 | 65.9 | 4.3 |
| 2004 | 15.6 | 19.7 | 64.7 | 6.4 |
| 2005 | 15.6 | 19.0 | 65.4 | 8.5 |
| 2006 | 15.4 | 18.3 | 66.3 | 13.0 |
| 2007 | 15.8 | 18.2 | 65.9 | 15.8 |
| 2008 | 15.7 | 16.6 | 67.7 | 18.5 |
| 2009 | 16.8 | 17.6 | 65.7 | 11.4 |

Source: EIA (2011a).

**Thermal energy generation**. As shown in Table 5.5, the main fuel inputs of thermal energy generation are natural gas and coal. The electricity generation sector in Russia is strongly reliant on natural gas. For example, in 2009, the share of natural gas in total demand for energy by thermal electricity generation amounted to 70.1%, followed by coal (27.8%), oil (2.0%), and other (0.1%) (Table 5.5). During the period from 2000 to 2009, the share of gas increased from 63.8% to 70.1%, whereas the share of coal decreased from 30.6% to 27.8%. The main reason for this is low domestic prices of gas (Ministry of Energy, 2011b).

**Table 5.5: Structure of Fuel Consumption by Thermal-Electric Generation (per cent)**

| | 2000 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|
| Gas | 63.8 | 70.3 | 69.2 | 71.2 | 69.7 | 70.1 |
| Coal | 30.6 | 26.4 | 26.9 | 26.2 | 28.3 | 27.8 |
| Oil | 5.1 | 2.7 | 3.3 | 2.0 | 1.9 | 2.0 |
| Others | 0.5 | 0.6 | 0.6 | 0.6 | 0.1 | 0.1 |
| **Total** | **100** | **100** | **100** | **100** | **100** | **100** |

Source: EFA (2009b).

The reorganization of the power generation sector in Russia started in 2001 (Government Decree No.526 from July 11th, 2001; RAO-EES, 2001). According to the reform, all generation companies were divided into two types: Generation Companies of the Wholesale Electricity Market (WGC) and Territorial Generation Companies (TGC). Almost all WGC are specializing in electricity generation, whereas TGC are specializing in electricity and heat production. Furthermore, all WGC companies have a larger capacity compared to TGC (Ministry of Energy, 2011b). The largest WGCs with respect to generation capacity are WGC-1, WGC-6 and WGC-5. Among TGCs, the largest companies are Mosenergo and TGC-1 (Table 5.6). At present, there are 24 main electricity generation companies, which are formed as joint stock companies (JSC) (Ministry of Energy, 2011b). Table 5.6 shows the technical and production characteristics of some of these companies. The generation companies consist of many affiliates and use different energy generation technologies. The majority of the power plants, however, are built as dual fuel plants (coal-gas). The main fuel input still remains natural gas, which is used by almost all thermal energy generation companies. Only JSC TGC-13 and TGC-14 are generating energy mainly using coal and alternatively using some oil products. The largest electricity producers among thermal energy companies are JSC Mosenergo, JSC WGC-4, and JSC WGC-2.

**Table 5.6: Technical and Production Characteristics of Russian Energy Generation Companies in 2008**

| JSC companies | Production in 2008 | | | Power capacity | | Stations | Workers | Fuel Balance |
|---|---|---|---|---|---|---|---|---|
| | Electricity, million kWth | Share in total, in % | Heat, thousand Gcal/h | MWt | Gcal/h | | | |
| Energoatom | 162,300 | 22.61 | n.a. | 25,200 | n.a. | 10 | 38,545 | Nuclear |
| RusHydro | 77,704 | 10.82 | n.a. | 24,372 | n.a. | 19 filial | 5,748 | Hydro |
| Mosenergo | 64,274 | 8.95 | 62,440 | 11,900 | 34,900 | CHP**:15<br>Hydro: 1 | 13,580 | Gas: 98.4%<br>Coal: 1.3%<br>Oil: 0.3% |
| WGC-4 | 56,676 | 7.89 | 2,261 | 8,630 | 2,179 | CHP: 5 | 5410 | Gas and Coal |
| WGC-2 | 49,827 | 6.94 | 2,338 | 8,695 | 1,834 | CHP: 5 | n.a. | Gas and Coal |
| WGC-1 | 46,349 | 6.46 | 1,226 | 9,531 | 2,788 | CHP: 6 | 5,835 | Gas: 91%<br>Coal: 8%<br>Oil: 1% |
| Enel WGC-5 | 43,005 | 5.99 | 6,819 | 8,732 | n.a. | CHP: 4 | 4,270 | Gas: 52%<br>Coal: 47%<br>Oil: 1% |
| WGC-3 | 33,912 | 4.72 | 1,570 | 8,357 | 1,615 | CHP: 6 | 7,500 | Gas: 57%<br>Coal: 41%<br>Oil: 2% |
| WGC-6 | 38,857 | 5.41 | 4,350 | 9,052 | 2,704 | CHP: 6 | 6,266 | Gas: 51.3%<br>Coal: 47.7%<br>Oil: 1% |
| TGC-1 | 26,888 | 3.75 | 23,905 | 6,279 | 14,548 | n.a. | 9,114 | Gas: 90%<br>Oil: 6%<br>Coal: 4% |
| Volshskaj TGC-7 | 22,548 | 3.14 | 37,495 | 5,851 | 25,946 | CHP: 21 | n.a. | Gas: 100% |
| Forum | 16,600 | 2.31 | 21,800 | 2,785 | 11,862 | CHP: 8 | 7,000 | Gas: 95%<br>Coal: 5% |
| TGC-9 | 16,340 | 2.28 | 40,388 | 3,279 | 16,666 | CHP: 21<br>Hydro: 2 | 10,201 | Gas: 70%<br>Coal: 30% |
| TGC-13 | 14,236 | 1.98 | 14,451 | 2,518 | 6,988 | CHP: 9 | 7,093 | Coal and Oil |
| TGC-6 | 13,083 | 1.82 | 16,884 | 3,112 | 10,689 | CHP: 11 | n.a. | Gas: 95%<br>Coal and Oil: 5% |
| TGC-4 Kvadra | 12,878 | 1.79 | 26,669 | 3,348 | 12,472 | CHP: 25 | 12,011 | Gas: 95%<br>Coal and Oil: 5% |
| TGC-2 | 10,530 | 1.47 | 19,993 | 2,577 | 12,770 | CHP: 15 | n.a. | n.a. |
| TGC-11 | 9,398 | 1.31 | 15,700 | 2,026 | 8,202 | CHP: 6 | 5,289 | Coal: 51.7%<br>Gas: 48.3% |
| TGC-14 | 2,501 | 0.35 | 6,531 | 633 | 3,175 | CHP: 7 | 4,857 | Coal and Oil |
| **Total** | **717,906** | **100** | **n.a.** | **n.a.** | **n.a.** | **n.a.** | **n.a.** | **n.a.** |

** CHP – combined heat and power stations.

Source: own calculation based on companies annual reports for 2008 which are available at companies' websites.

**Hydroelectric energy generation.** The second most important source of electricity generation is hydro power, whose share accounts for 18% of total electricity generation in Russia (Table 5.4). The share of nuclear has slightly increased, whereas the share of hydroelectric has declined recently. At present, there are 102 hydroelectric stations running in

Russia. Russia faces a large potential to enlarge its hydroelectric generation, because it uses only approximately 20% of total hydro power potential. Furthermore, Russia has approximately 9% of the world's hydro power resources. The main problem is a large distance between the main hydroelectric producers, such as Siberian and Far East regions and the largest consumers of energy, such as Central and South regions (Ministry of Energy, 2011b). More than 50% of the total installed hydroelectric capacity in Russia is concentrated in one single company, JSC RusHydro. The government has a property share of 57.97% in the company's capital stock. JSC RusHydro is the largest hydro company in Russia, which concentrates more than 50% of the total hydro power capacity. JSC RusHydro is the world's second largest hydro-power company after Hydro Qebec with respect to the installed capacity (RusHydro, 2009).

**Nuclear energy generation.** Another large source of electricity generation is nuclear energy. The nuclear energy sector is represented by a sole company, JSC Rosenergoatom. At present, 10 nuclear stations with 31 nuclear reactors are operation in Russia, and 5 stations are under construction (Rosenergoatom, 2009). The production share of nuclear energy is 16% in total electricity generation (Table 5.4). Nuclear electric stations are mainly located in the western part of Russia (Ministry of Energy, 2011b). JSC Rosenergoatom and JSC RusHydro are the largest electricity producing companies in Russia with respect to power capacity.

### 5.4.2 Demand

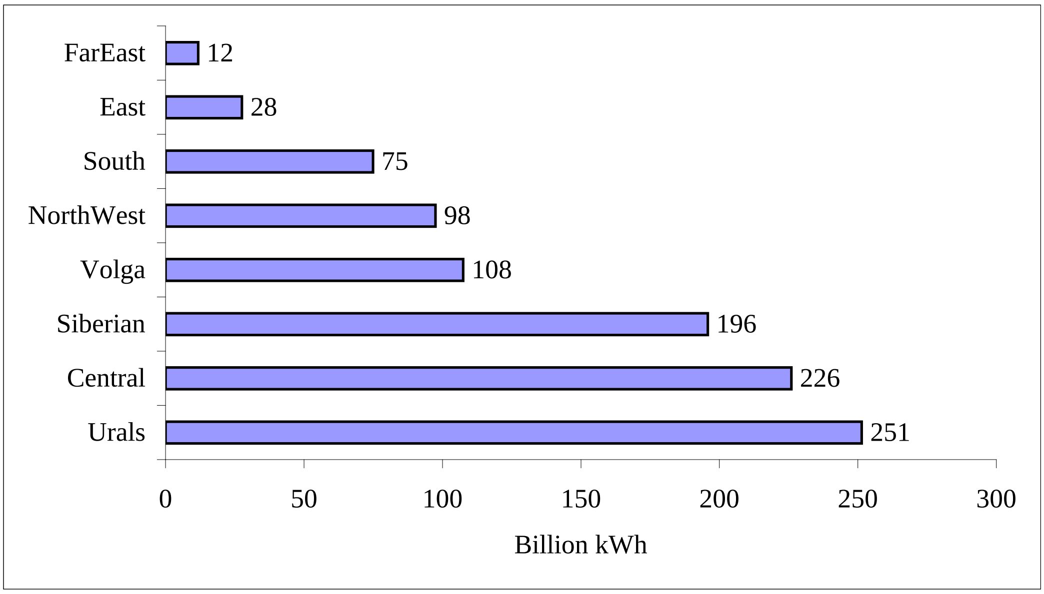
The whole Russian electricity market can be divided into three regional markets: (1) European regional Market, (2) Siberian regional market, and (3) Non-pricing regional market. These regional markets are weakly interrelated with each other because of an underdeveloped network infrastructure. In addition, the regional markets differ significantly with respect to their power capacity and applied technologies of electricity generation (Ministry of Energy, 2011b). The European regional market includes regions (okrug), the Northwest, Volga (Privolzhskiy), Central, South (Northern Caucasus) and Urals (Figure 5.7).

**Figure 5.7: Map of Russian Regions**

Source: NSP (2010).

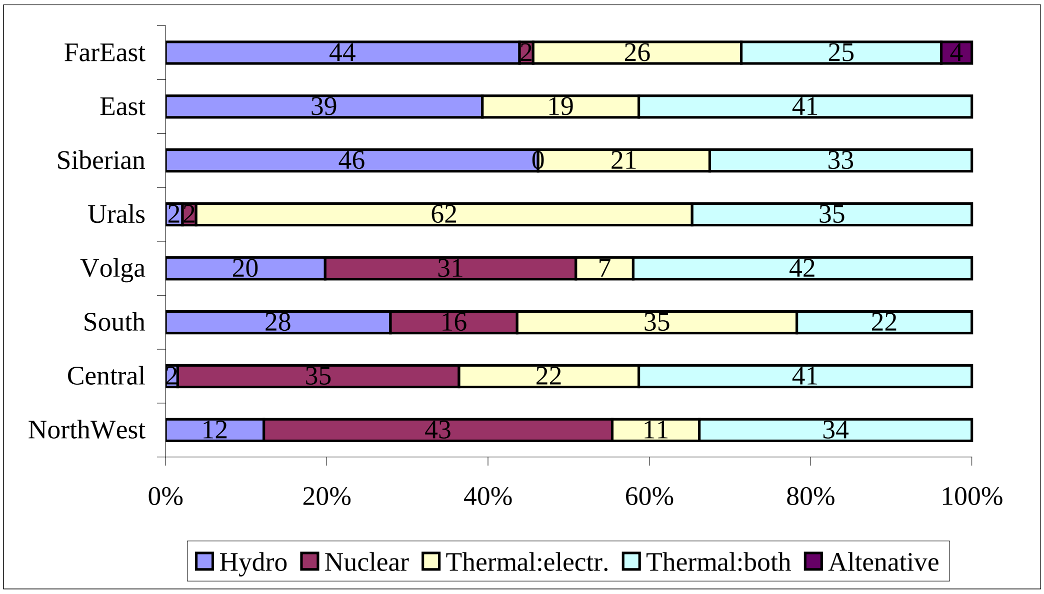
**European regional market.** As shown in Figure 5.8, the European regional market is the largest electricity market in Russia in terms of electricity consumption. Its power capacity amounted to 72-75% of total power capacity in 2007 since the most energy intensive industries, such as metallurgy and mining, are concentrated in this region. Electricity generation stations are quite homogenously distributed within this regional market with different electricity generation technologies (Ministry of Energy, 2011b). The main sources of electricity in the European regional market are thermal energy and nuclear (Figure 5.8).

**Figure 5.8: Electricity Consumption by Region in 2007 (billion kWh)**



Source: EFA (2009b).

**Figure 5.9: Structure of Electricity Generation by Russian Regions in 2010* (per cent)**



* Forecasts based on data from 2007.

Source: EFA (2009b).

**Siberian regional market.** The Siberian regional market concentrates approximately 20% of total power capacity. The largest source of electricity generation is hydro: for example, the production share of hydroelectricity was 46% of total electricity generated in 2010 (Figure 5.9). Moreover, there is a large potential to enlarge coal and hydro power in this region. Thermal energy generation in the Siberian regional market is mainly represented by coal-fired technologies. According to the *Russian Energy Strategy*, it is planned to enlarge coal and hydro power generation in Siberia and Far East to decrease the energy dependency on natural gas. The Siberian regional market is relatively low interrelated with the European regional market because of underdeveloped infrastructure between these markets. The Siberian regional market as well as the European regional market have large numbers of producers and consumers of electricity and heat with relatively well developed network infrastructure within these regions (Ministry of Energy, 2011b).

**Non-pricing regional market.**[28] The least developed market is the Non-pricing regional market, which is located in the Far East region. Its power capacity amounts to about 10% of total power capacity. This market faces quite outdated network infrastructure, and it is almost not interrelated with other regional markets (Ministry of Energy, 2011b). The main sources of energy generation are hydro power and thermal energy (Figure 5.9).

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[28] Non-pricing markets is a direct translation from Russia. This term implies that prices of electricity are regulated by the government for all demand categories.

**Domestic consumers of electricity.** Industries are the largest domestic consumer of electricity in Russia, whose share accounted for 54.6% of total electricity consumption in 2009, followed by households (12.4%), and losses of electricity in networks (11.3%) (FSSS, 2010). Among industries, the most electricity intensive sector are metals, whose consumption shares accounted for 30.3% of total electricity consumption by industries in 2009, followed by extraction of oil and gas (17.7%), production and distribution of electricity (14.5%), and chemical products (7.5%). In addition, the share of electricity consumption by the extraction of oil and gas sector has considerably increased from 2005 to 2003 from 12.8% to 17.7% because of increased production in this sector.

**Table 5.7: Electricity Consumption by Industries (per cent)**

| | **2005** | **2006** | **2007** | **2008** | **2009** |
|---|---|---|---|---|---|
| Extraction of coal | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 |
| Extraction of oil and gas | 12.8 | 13.7 | 14.5 | 15.2 | 17.7 |
| Minerals | 5.0 | 5.1 | 5.1 | 4.7 | 4.9 |
| Food products | 3.0 | 3.1 | 2.9 | 3.0 | 3.0 |
| Textile products | 0.8 | 0.7 | 0.6 | 0.8 | 0.5 |
| Paper, publishing | 3.5 | 3.5 | 3.4 | 4.5 | 3.6 |
| Oil products | 4.2 | 3.7 | 3.5 | 3.3 | 3.8 |
| Chemical products | 7.4 | 7.7 | 7.4 | 7.5 | 7.5 |
| Plastic material | 0.9 | 0.7 | 0.8 | 1.0 | 0.7 |
| Non-metal minerals | 3.2 | 3.4 | 3.7 | 3.9 | 3.3 |
| Metals and metal products | 30.9 | 30.8 | 31.1 | 31.1 | 30.3 |
| Machinery equipment | 1.9 | 1.9 | 2.1 | 1.8 | 1.5 |
| Electronic equipment | 1.3 | 1.1 | 1.1 | 1.2 | 0.9 |
| Transport equipment | 2.6 | 2.4 | 2.4 | 2.3 | 1.7 |
| Production and distr. of electricity | 17.6 | 16.8 | 15.9 | 13.7 | 14.5 |
| Production and distr. of water | 2.5 | 3.0 | 3.2 | 3.4 | 3.8 |
| Others | 1.1 | 3.8 | 3.6 | 3.7 | 3.6 |
| **Total** | **100** | **100** | **100** | **100** | **100** |

Source: Own calculation based on FSSS (2010).

In the domestic market, electricity is sold according to long-term contracts (take or pay), which can be either regulated or non-regulated. In the case of regulated contracts, the domestic prices of electricity are regulated by the Federal Tariff Services. Since January 2011 electricity for industries is sold for non-regulated prices (Government Decree No.205 from April 7th, 2007), whereas domestic prices of electricity and heat for households are still administratively regulated. Regulated prices of electricity for households are lower than prices for industries. Recently, regulated prices for households were increased in order to reduce price differences between industries and households (Ministry of Economics, 2008). Moreover, electricity prices for households differ by region, where the highest prices are imposed in Far East and Central regions of Russia (FTS, 2011).

### 5.4.3 Challenges for Electricity Policy

According to the *Russian Energy Strategy up to 2030* (Ministry of Energy, 2009), the main challenges for the Russian power generation sector are summarized as follows:

1) Development of a grid network between the regions, such as Siberia, Ural, and Centre to provide an effective redistribution of energy between regions.
2) Technical and technological modernization of the power generation sector, especially installation of new low carbon-intensive generation technologies.
3) Diversification of the energy balance from gas-fired to coal-fired generation since the electricity generation in Russia strongly depends on natural gas.
4) Encouragement of more competition in the domestic electricity market.

**Technical modernization.** One of the most important issues for the power generation sector as well as the whole economy is a large-scale modernization of the capital stock. Modernization of the power generation sector, however, is a costly and slow process. For instance, according to the *General Plan of Power Plants Location until 2030*, it is planned to replace approximately 51.9 GW of power plant capacity up to 2030. According to estimations based on company reports, however, this will take place only 26% of the planned capacity replacement (EFA, 2009b). According to the director of the Energy Forecasting Agency, Kozuchowski (2008), the technical modernization of the Russian power generation sector is slowed down due to economic reasons, such as high capital costs and low energy prices. Technical replacement could be delayed via technical reparation, especially in capital intensive sectors such as the power generation sector. Under current economic conditions, it is more economically efficient for companies to repair some old power plants than replace them. This is because energy inputs such as natural gas and coal products are quite cheap, whereas capital costs of new power generation plants are high. In addition, investment in new power plants implies uncertainties and high risk regarding future energy demand and prices of energy inputs. Slow technical modernization of the power generation sector is associated with high reparation costs and high demand for energy resources (Kozuchowski, 2008).

Modernization of the power generation sector requires large financial resources. Among thermal power generation companies, on average more than 50% of total investment is financed through external investment sources such as credits, whereas other 50% are financed through company profits and fiscal depreciation. Hydro and nuclear power generation in Russia are mainly represented by two companies, which are basically state run with government's property share being more than 50% of capital stock. Therefore, investment in nuclear and hydro generation is mainly financed by the government (Makarov et al., 2008).

**Price regulation.** Reformation of the power generation sector is an important aspect of the energy policy in Russia. At present, the electricity market in Russia is almost liberalized. Since 2011 domestic prices of electricity for industries are not regulated anymore. Moreover, the Russian government plans gradually to eliminate the regulation of electricity prices for households in the long run. According to the *Long Run Project of Social and Economical Development in Russia*, domestic prices of electricity for households will be regulated until 2014 (Ministry of economics, 2008). Regulation of electricity prices for households leads to cross subsidization effects. In Russia, three kinds of cross subsidization can be distinguished: (1) regional cross subsidization, (2) sectoral cross subsidization and (3) cross subsidization between heat and electricity. The sectoral cross subsidizing effect occurs via regulation of electricity prices for households, whereas electricity prices for industries are not regulated. As a result, low electricity prices for households are indirectly "subsidized" by higher electricity prices for industries, which lead to overconsumption of electricity by households and underconsumption by industries. In addition, cross subsidization increases production costs in industries and, therefore, increase prices of other products. Regulation of domestic prices of heat also leads to a cross subsidization effect between electricity and heat so that relatively high prices of electricity subsidize low prices of heat. Similarly with regional cross subsidization, where some regions pay higher electricity prices compared to others (Bogdanov, 2009). An earlier liberalization of the electricity and heat market in Russia was politically undesirable. This is because the poorest households will be affected most adversely by higher electricity prices. Moreover, one can raise concerns about an oligopolistic structure of the electricity market (Pittman, 2006).

**Energy balance.** The electricity sector is strongly reliant on natural gas, which is the main energy input in Russia. According to the *Russian Energy Strategy up to 2030* (Ministry of Energy, 2009), it is planned to diversify the structure of power generation in Russia in favour of coal and oil via an increase in domestic prices of gas. Table 5.8 shows the projected structure of energy inputs used by the electricity sector up to 2030. For example, the consumption share of natural gas is planned to be reduced from 71% to 62% of total energy inputs used by the electricity sector.

**Table 5.8: Projected Structures of Energy Inputs Used by the Electricity Generation Sector (per cent in total energy demand)**

| | **1 State** | **2 State** | **3 State** |
|---|---|---|---|
| | 2009-2015 | 2015-2020 | 2020-2030 |
| Natural gas | 70-71 | 65-66 | 60-62 |
| Coal | 25-26 | 29-30 | 34-36 |
| Other | 5-3 | 6-4 | 6-2 |

Source: Ministry of Energy (2009).

## 5.5 Summary of the Chapter

The Russian economy strongly relies on energy markets. One of the main objectives of energy policy is to ensure an efficient and sustainable use of energy resources. As discussed above, the main challenge of the Russia energy sector is a large-scale modernization of outdated capital stock, which is one of the main reasons for high carbon/energy intensity of the Russian economy. Another important aspect is the structure of energy markets. Energy markets in Russia are far from being perfectly competitive. In particular, gas and oil markets are strongly oligopolized by a small number of large vertically integrated companies. For example, the Russian gas market is dominated by the state run company Gazprom, which has market power on export markets. While petroleum and coal markets are completely liberalized, reforming the natural gas and electricity market is still in process: domestic prices of electricity and natural gas are regulated by the government.

# 6 Database and Model Framework

The theoretical literature on environmental taxation suggests that a general equilibrium framework is an appropriate method to analyse the economic and distributional effects of environmental tax reform. This is because general equilibrium models allow analysing various policy simulations in the presence of pre-existing distortions such as taxes and imperfect competition. Moreover, they provide an explicit link between output and factor markets. While analytical general equilibrium models are aimed at determining the key factors which drive the results, numerical computable general equilibrium (CGE) models are able to capture real-world complexities. Hence, a CGE model is employed for this analysis to quantify the effects of the introduction of carbon taxes in Russia under different revenue recycling schemes.

Chapter 6 provides a description of the database as well as the model framework applied. The chapter is divided into four parts. The first part gives some summary statistics from the benchmark dataset in order to provide intuition for results interpretation. The parameterization of the model is also introduced in this part. The second part deals with adjustments of the database such as the database aggregation, calculation of carbon coefficients, and disaggregation of the power generation sectors. In the third part, the core model is described with respect to price and quantity system as well as production system. The last part describes the model modifications.

## 6.1 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 account, and a single private household is represented. For our analysis, a Social Accounting Matrix (SAM) for Russia is extracted using the GAMS version of the SAM extraction program developed by McDonald and Thierfelder (2004).

Furthermore, the satellite energy database for the Version 7 of the GTAP database is used to calculate absolute changes in energy use by industries and households. The energy database provides information on sectoral and household energy consumption measured in million tons of oil equivalent (Mtoe). The changes in sectoral demand for energy are calculated by multiplying the initial level of energy consumption with relative changes in energy demand resulting from policy simulations. To calculate the carbon dioxide coefficients, the satellite emission database for the Version 7 of the database (Lee, 2008) is used, which measures carbon dioxide emissions in Giga gram (Gg).

## 6.1.1 Overview of the Database

### 6.1.1.1 Energy Consumption

Sectoral effects of carbon taxes strongly depend on energy as well as factor intensity of industries. Table 6.1 shows the cost structure of industries as well as trade shares. According to Version 7 of the GTAP database (2007), the most energy intensive sectors are the petroleum products sector in terms of high consumption of crude oil, and the electricity sector in terms of high consumption of gas, coal, and petroleum products. For example, the share of energy costs in production of petroleum products accounts for 90.9% of total production costs and for the electricity sector it is 72.3%. Apart from energy sectors, other energy intensive sectors are wood products, whose share of energy costs accounts for 47.4% of total production costs, followed by chemical products (37.6%), transports (25.3%), and metals (21%). These sectors are mainly energy intensive in terms of high consumption of electricity. The most capital intensive sectors are trade commodities, whose share of capital costs accounts for 61.4% of total production costs, followed by private services (36.3%), crude oil (36.5%), minerals (29.5%), and construction (28.1%). The most labour intensive sectors are public services, whose share of labour costs accounts for 53.4% of total production costs, followed by agriculture (45.6%), water (39.5%), coal (38.7%), gas manufacture (37.2%), and machinery equipment (29.3%).

**Table 6.1: Shares in Production Costs and Trade Shares (per cent)**

| | Production cost shares | | | | Trade shares | |
|---|---|---|---|---|---|---|
| | **Energy share** | **Capital share**[a] | **Labour share** | **Intermediate share** | **Import share** | **Export share** |
| Coal | 10.2 | 24.8 | 18.6 | 47.2 | 16.3 | 38.8 |
| Crude oil | 2.4 | 60.9 | 6.8 | 29.8 | 1.0 | 52.6 |
| Natural gas | 6.6 | 33.5 | 5.8 | 54.5 | 2.7 | 15.1 |
| Petroleum products | 90.9 | 4.9 | 1.2 | 2.9 | 0.4 | 20.8 |
| Gas manufacturing | 9.5 | 16.0 | 37.2 | 37.9 | 0.1 | 20.1 |
| Electricity | 72.3 | 8.0 | 5.6 | 14.0 | 1.0 | 0.9 |
| Wood products | 47.4 | 3.1 | 11.5 | 38.3 | 43.3 | 40.5 |
| Chemical products | 37.6 | 8.3 | 10.5 | 43.6 | 45.5 | 44.8 |
| Mineral products | 20.8 | 10.1 | 20.4 | 49.0 | 18.4 | 6.0 |
| Metals | 20.9 | 16.8 | 9.5 | 52.5 | 13.8 | 51.3 |
| Metal products | 10.6 | 7.3 | 22.8 | 59.7 | 35.9 | 18.2 |
| Electronic equipment | 14.3 | 8.6 | 12.1 | 65.1 | 80.4 | 18.0 |
| Transports | 25.3 | 21.5 | 19.2 | 34.0 | 11.9 | 15.7 |
| Machinery equipment | 8.1 | 8.6 | 29.3 | 54.4 | 40.3 | 14.5 |
| Water | 15.6 | 13.6 | 39.5 | 32.0 | 0.6 | 0.5 |
| Agriculture | 6.2 | 23.3 | 31.3 | 40.1 | 10.2 | 7.1 |
| Food products | 4.6 | 13.6 | 8.6 | 73.1 | 21.9 | 8.3 |
| Construction | 1.5 | 27.9 | 21.8 | 48.6 | 4.4 | 2.0 |
| Trade | 1.1 | 60.1 | 8.0 | 29.4 | 1.7 | 0.8 |
| Transport equipment | 0.05 | 5.0 | 11.7 | 83.4 | 48.7 | 25.0 |
| Private services | 4.9 | 36.0 | 25.2 | 33.6 | 13.5 | 6.7 |
| Public services | 3.2 | 10.9 | 53.4 | 33.6 | 3.0 | 0.5 |
| Minerals | 0.2 | 36.3 | 19.2 | 44.3 | 16.4 | 31.3 |
| Textiles | 5.8 | 8.6 | 19.1 | 66.9 | 62.7 | 18.4 |
| Paper products | 0.7 | 20.8 | 9.8 | 68.4 | 36.6 | 28.2 |

[a] The capital share includes cost on natural resources and land.

Source: Own calculations based on Version 7 of the GTAP database.

#### 6.1.1.2 $CO_2$ Emissions and Energy Consumption

Table 6.2 shows data on $CO_2$ emissions by industries and the representative household. According to the database, over half (55.1%) of $CO_2$ emissions in Russia comes from the electricity sector. Out of this total, 32.3%, 42.2% and 17.4% stem from the coal, natural gas and gas manufacture, respectively. Other important sources of $CO_2$ emissions are the household (14.1%) and the transport sector (13.2%). According Lee (2008), the largest source of $CO_2$ emissions in Russia is the use of natural gas with a share of 33.8% of total $CO_2$ emissions, followed by petroleum products (23.0%), gas manufacture (22.5%), coal (20.0%), and crude oil (0.7%).

**Table 6.2: Sources of Carbon Dioxide Emissions**

| | $CO_2$ emissions | | Per cent of total $CO_2$ by sectors | | | | |
|---|---|---|---|---|---|---|---|
| | Giga gram | Per cent of total $CO_2$ emission | Coal | Crude oil | Natural gas | Petroleum products | Gas manufacture |
| Coal | 1647 | 0.1 | 99.9 | 0.0 | 0.0 | 0.0 | 0.1 |
| Crude oil | 17276 | 1.1 | 0.0 | 25.1 | 56.3 | 4.4 | 14.2 |
| Natural gas | 25272 | 1.6 | 0.0 | 8.7 | 88.8 | 2.3 | 0.2 |
| Petroleum products | 23431 | 1.5 | n.a.[a] | n.a. | 88.6 | n.a. | 11.4 |
| Gas manufacture | 1257 | 0.1 | 0.9 | 8.2 | n.a. | 20.1 | 70.8 |
| Electricity | 855234 | 55.1 | 32.3 | 0.3 | 42.2 | 7.8 | 17.4 |
| Wood products | 1736 | 0.1 | 1.4 | 0.1 | 0.0 | 97.5 | 1.0 |
| Chemical products | 34276 | 2.2 | 0.1 | 0.0 | 11.4 | 65.0 | 23.5 |
| Mineral products | 21071 | 1.4 | 8.2 | 0.0 | 61.4 | 10.2 | 20.2 |
| Metals | 61806 | 4.0 | 7.9 | 0.4 | 38.4 | 31.8 | 21.6 |
| Metal products | 1821 | 0.1 | 1.4 | 0.1 | 17.5 | 56.4 | 24.6 |
| Electronic equipment | 625 | 0.0 | 0.9 | 0.1 | 0.0 | 76.9 | 22.2 |
| Transports | 204781 | 13.2 | 0.1 | 0.1 | 27.1 | 57.6 | 15.2 |
| Machinery equipment | 4979 | 0.3 | 3.8 | 0.1 | 39.9 | 10.9 | 45.2 |
| Water | 1315 | 0.1 | 23.1 | 0.0 | 0.4 | 73.5 | 3.1 |
| Agriculture | 16348 | 1.1 | 2.9 | 0.2 | 6.0 | 89.1 | 1.8 |
| Food products | 5829 | 0.4 | 9.0 | 0.2 | 17.1 | 49.2 | 24.4 |
| Construction | 4103 | 0.3 | 2.8 | 1.9 | 3.2 | 74.9 | 17.3 |
| Trade products | 9150 | 0.6 | 10.8 | 0.0 | 6.5 | 74.4 | 8.3 |
| Transport equipment | 69 | 0.0 | 8.0 | 3.9 | 31.5 | 8.4 | 48.1 |
| Private services | 24014 | 1.5 | 2.0 | 0.6 | 5.1 | 84.5 | 7.8 |
| Public services | 15604 | 1.0 | 19.9 | 0.0 | 6.1 | 39.6 | 34.4 |
| Minerals | 104 | 0.0 | 1.6 | 4.1 | 30.0 | 51.6 | 12.7 |
| Textiles | 267 | 0.0 | 13.1 | 1.5 | 16.1 | 13.6 | 55.7 |
| Paper products | 934 | 0.1 | 0.7 | 0.1 | 26.4 | 3.0 | 69.8 |
| Household | 219520 | 14.1 | 8.8 | 0.0 | 3.6 | 31.1 | 56.5 |
| **Total** | 1552470 | 100 | n.a. | n.a. | n.a. | n.a. | n.a. |

[a] n.a. states for non available, which means no $CO_2$ emissions are recorded. Source: Own calculation based on Lee (2008).

Table 6.3 shows the shares of energy consumption by various demand categories. Domestic energy markets in Russia are mainly served by domestic producers. For example, the share of domestically produced coal accounts for 83.7% of total domestic consumption of coal, whereas the domestic shares of other energy commodities are considerably larger compared to that of coal – more than 97% of total domestic consumption. The electricity sector is the largest domestic consumer of coal, natural gas, and gas manufacture as well as one of the largest consumers of petroleum products. For example, the electricity sector consumes about 65.3% of total domestically sold coal, 68% of natural gas, 42.2% of gas manufacture, and 18.9% of petroleum products. The largest domestic consumer of crude oil is the petroleum products sector with a share of 97.8% of total domestic consumption of crude oil.

**Table 6.3: Value Shares of Energy Consumption (per cent)**

| | **Coal** | **Crude oil** | **Natural gas** | **Petroleum products** | **Gas manufac.** | **Electricity** |
|---|---|---|---|---|---|---|
| **Domestic shares** | 83.69 | 98.75 | 97.32 | 99.64 | 99.91 | 98.97 |
| Coal | 0.38 | 0.00 | 0.00 | 0.00 | 0.00 | 1.05 |
| Crude oil | 0.00 | 0.93 | 1.22 | 0.15 | 0.69 | 2.11 |
| Natural gas | 0.00 | 0.47 | 2.81 | 0.11 | 0.01 | 0.75 |
| Petroleum products | 23.15 | 97.82 | 2.60 | 14.42 | 0.75 | 3.12 |
| Gas manufacturing | 0.00 | 0.02 | 0.23 | 0.05 | 0.25 | 1.65 |
| Electricity | 65.31 | 0.61 | 68.04 | 18.94 | 42.24 | 2.67 |
| Wood products | 0.01 | 0.00 | 0.00 | 0.36 | 0.00 | 3.77 |
| Chemical products | 0.01 | 0.00 | 6.43 | 6.66 | 2.29 | 9.07 |
| Mineral products | 0.41 | 0.00 | 2.89 | 0.45 | 1.22 | 1.61 |
| Metals | 1.16 | 0.05 | 4.74 | 4.15 | 3.83 | 13.50 |
| Metal products | 0.01 | 0.00 | 0.06 | 0.22 | 0.13 | 0.89 |
| Electronic equipment | 0.00 | 0.00 | 0.00 | 0.10 | 0.04 | 0.43 |
| Machinery equipment | 0.04 | 0.00 | 0.44 | 0.11 | 0.65 | 4.93 |
| Water | 0.09 | 0.00 | 0.00 | 0.20 | 0.01 | 1.55 |
| Transports | 0.05 | 0.03 | 8.66 | 24.91 | 8.99 | 4.58 |
| Agricultural products | 0.11 | 0.01 | 0.20 | 3.08 | 0.09 | 2.42 |
| Food products | 0.12 | 0.00 | 0.13 | 0.61 | 0.41 | 3.13 |
| Construction | 0.03 | 0.02 | 0.02 | 0.65 | 0.20 | 1.11 |
| Trade products | 0.23 | 0.00 | 0.08 | 1.44 | 0.22 | 1.15 |
| Transport equipment | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 |
| Private services | 0.16 | 0.03 | 0.21 | 4.28 | 0.58 | 2.07 |
| Public services | 1.19 | 0.00 | 0.20 | 1.30 | 1.74 | 3.49 |
| Minerals | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 |
| Textiles | 0.01 | 0.00 | 0.01 | 0.01 | 0.04 | 0.70 |
| Paper products | 0.00 | 0.00 | 0.04 | 0.01 | 0.19 | 0.03 |
| Households | 7.53 | 0.00 | 1.00 | 17.79 | 35.43 | 34.19 |
| **Total** | **100** | **100** | **100** | **100** | **100** | **100** |

Source: Own calculation based on Version 7 of GTAP database (2007).

### 6.1.1.3 Tax Rates

The database provides information on the main policy instruments, such as trade taxes, consumption taxes, taxes on factor income, and taxes on factor use. Consumption taxes include value added taxes and excise taxes. Taxes on factor income are taxes on income from capital, labour, land and natural resources. Capital taxes include corporate income taxes, taxes on interest from bank deposits and dividends. Social security contributions are represented by taxes on labour use, which are paid by industries.

### 6.1.1.4 Parameterization

Table 6.4 summarises elasticities of substitution between import and domestically products commodities (Armington elasticities), elasticities of transformation between export and domestic supply (CET elasticities), and elasticities of substitution among primary factors.

**Table 6.4: Armington Elasticities, CET Elasticities and Elasticities of Substitution**

| | Armington elasticities | CET elasticities | Elasticities of substitution among primary factors |
|---|---|---|---|
| Coal | 1.52 | 2.90 | 0.20 |
| Crude oil | 2.60 | 2.90 | 0.20 |
| Natural gas | 8.60 | 2.90 | 0.20 |
| Petroleum products | 1.05 | 2.90 | 1.26 |
| Gas manufacturing | 1.40 | 2.90 | 1.26 |
| Electricity | 1.40 | 2.90 | 1.26 |
| Wood products | 1.70 | 2.00 | 1.26 |
| Chemical products | 1.65 | 2.00 | 1.26 |
| Mineral products | 1.45 | 2.00 | 1.26 |
| Metals | 1.79 | 2.00 | 1.26 |
| Metal products | 1.87 | 2.00 | 1.26 |
| Electronic equipment | 2.65 | 2.00 | 1.26 |
| Transports | 0.95 | 2.00 | 1.57 |
| Machinery equipment | 1.95 | 2.00 | 1.26 |
| Water | 1.40 | 2.00 | 1.26 |
| Agricultural products | 1.45 | 1.50 | 0.22 |
| Food products | 1.48 | 1.50 | 1.12 |
| Construction | 2.53 | 2.00 | 1.40 |
| Trade products | 0.95 | 2.00 | 1.68 |
| Transport equipment | 1.78 | 2.00 | 1.26 |
| Private services | 0.59 | 2.00 | 1.26 |
| Public services | 0.95 | 2.00 | 1.26 |
| Minerals | 0.45 | 2.00 | 0.20 |
| Textiles | 1.36 | 2.00 | 1.26 |
| Paper products | 1.48 | 2.00 | 1.26 |

**Armington elasticities.** Armington elasticities in the GTAP database are not country specific. To our knowledge, empirical estimations on Armington elasticities for Russia are scarce.

Probably, this is because of structural changes in the Russian economy in 90ies resulting from the collapse of the Soviet Union. This makes empirical estimations difficult because of a lack of appropriate time series. There are, however, some estimates of Armington elasticities for several commodities for Russia. For example, Ivanova (2005) estimated the Armington elasticities for textiles, clothing, footwear, furniture, electric household appliances, vehicles, and construction materials. Zemnitsky (2002) provides an estimation of the Armington elasticity for private services in Russia. Therefore, these estimated values are taken; otherwise elasticities are taken from the Version 7 of the GTAP database.

**CET elasticities.** Elasticities of transformation (CET elasticities) are taken from Wehrheim (2003). His CET elasticities are not specific for Russia, but they are based on empirical estimations carried out by Faini (1998) as well as elasticities used in other CGE models for other middle income countries (Banse, 1997; Weyerbrock, 1998; Wiebelt, 1996). The values of CET elasticities used in our analysis are the following: energy sectors (2.9), industries (2.0), and the agricultural and food sectors (1.5).

**Elasticities of substitution.** Elasticities of substitution used in production nesting structures are reported in Table 6.5. For example, elasticities of substitution between primary factors are taken from Version 7 of the GTAP database (Table 6.4), for more detail regarding the implemented nesting structures see Chapter 8.

**Table 6.5: Elasticities of Substitution**

| | Non-energy | Energy | Alternate Non-energy |
|---|---|---|---|
| $\sigma_X$ (the elasticity of substitution between the value added-energy aggregate and intermediate) | 0.5 | 0.5 | 0.5 |
| $\sigma_{VAE}$ (the elasticity of substitution between the labour aggregate and the value added-energy aggregate) | GTAP | GTAP | GTAP |
| $\sigma_{VLL}$ (the elasticity of substitution between primary factors such as labour, land and natural resources) | GTAP | GTAP | GTAP |
| $\sigma_{VKE}$ (the elasticity of substitution between capital and the energy aggregate) | 0.5 | 0.0 | 0.0 or 0.5 |
| $\sigma_{VE}$ (the elasticity of substitution between electricity and the non-electricity aggregate) | 1.0 | 0.0 | 0.0 or 0.5 |
| $\sigma_{VNEL}$ (the elasticity of substitution between coal and the non-coal aggregate) | 0.5 | n.a. | n.a. |
| $\sigma_{VNCO}$ (the elasticity of substitution within the non-coal aggregate) | 1.0 | n.a. | n.a. |

## 6.1.2 Adjustments of the Database

### 6.1.2.1 Sectoral Aggregation of the Database

57 activities are aggregated into 25 activities. The extracted SAM for Russia represents single product activities. Therefore, the mapping for commodities is equivalent to the mapping for activities, i.e., 57 commodities are aggregated into 25 commodities. Table 6.6 shows the map between the base accounts of the GTAP database and the aggregated accounts for the Russian SAM.

**Table 6.6: Mapping from the GTAP Accounts to the Aggregated Accounts in the SAM**

| Base accounts | Description of the Base Accounts | Aggregated Accounts | Description of the Aggregated Accounts |
|---|---|---|---|
| pdr | Paddy rice | agric | Agriculture |
| wht | Wheat | agric | Agriculture |
| gro | Cereal grains nec* | agric | Agriculture |
| v_f | Vegetables fruit nuts | agric | Agriculture |
| osd | Oil seeds | agric | Agriculture |
| c_b | Sugar cane sugar beet | agric | Agriculture |
| pfb | Plant based fibers | agric | Agriculture |
| ocr | Crops nec | agric | Agriculture |
| ctl | Bovine cattle sheep and goats horses | agric | Agriculture |
| oap | Animal products nec | agric | Agriculture |
| rmk | Raw milk | agric | Agriculture |
| wol | Wool silk worm cocoons | agric | Agriculture |
| frs | Forestry | agric | Agriculture |
| fsh | Fishing | agric | Agriculture |
| coa | Coal | coa | Coal |
| oil | Oil | oil | Oil |
| gas | Gas | gas | Gas |
| omn | Minerals nec | min | Minerals nec |
| cmt | Bovine cattle sheep and goat horse meat prods | food | Food products |
| omt | Meat products nec | food | Food products |
| vol | Vegetable oils and fats | food | Food products |
| mil | Dairy products | food | Food products |
| pcr | Processed rice | food | Food products |
| sgr | Sugar | food | Food products |
| ofd | Food products nec | food | Food products |
| b_t | Beverages and tobacco products | food | Food products |
| tex | Textiles | tex | Textiles |
| wap | Wearing apparel | tex | Textiles |
| lea | Leather products | tex | Textiles |
| lum | Wood products | wood | Wood products |
| ppp | Paper products, publishing | ppp | Paper products |
| p_c | Petroleum, coal products | p_c | Petroleum products |
| crp | Chemical, rubber, plastic products | crp | Chemical, rubber, plastic products |
| nmm | Mineral products nec | minp | Mineral products |
| i_s | Ferrous metals | metl | Metals |
| nfm | Metals nec | metl | Metals |
| fmp | Metal products | metlp | Metal products |

| | | | |
|---|---|---|---|
| mvh | Motor vehicles and parts | transe | Transport equipment |
| otn | Transport equipment nec | transe | Transport equipment |
| ele | Electronic equipment | ele | Electronic equipment |
| ome | Machinery and equipment nec | mache | Machinery and equipment |
| omf | Manufactures nec | mache | Machinery and equipment |
| ely | Electricity | ely | Electricity |
| gdt | Gas manufacture, distribution | gdt | Gas manufacture |
| wtr | Water | wtr | Water |
| cns | Construction | cns | Construction |
| trd | Trade | trad | Trade |
| otp | Transport nec | trans | Transports |
| wtp | Sea transport | trans | Transports |
| atp | Air transport | trans | Transports |
| cmn | Communication | trans | Transports |
| ofi | Financial services nec | servp | Private services |
| isr | Insurance | servp | Private services |
| obs | Business services nec | servp | Private services |
| ros | Recreation and other services | servp | Private services |
| osg | PubAdmin, defense, health, educat | servg | Public services |
| dwe | Dwellings | servg | Public services |

* nec – not elsewhere classified.

Sources: Own compilation.

For example, all agricultural and food products in the GTAP database are aggregated into two single groups: “Agriculture” and “Food products”. All transport sectors such as “Sea transport”, “Air transport”, “Transport nec” and “Communication” are aggregated into a single sector “Transports”. All services are aggregated into two groups namely “Private services” and “Public services”. The private services sector in the aggregated SAM for Russia includes “Financial services nec”, “Insurance”, “Business services nec”, and “Recreation services nec”, whereas the public services sector includes “Public Administration, Defence, Health, Education”, and “Dwellings”.

#### 6.1.2.2 Calculation of $CO_2$ Coefficients

Carbon taxes are imposed on the use of energy inputs by industries and households according to their $CO_2$ coefficients, which are determined by carbon intensity and energy prices. $CO_2$ coefficients are calculated based on the GTAP emission database (Lee, 2008), by dividing the $CO_2$ emission of a certain energy product (measured in Giga gram) by the value recorded in the GTAP database (measured in million USD). Table 6.7 shows the calculated $CO_2$ coefficients for energy inputs.

**Table 6.7: $CO_2$ Coefficients (giga gram per million USD)**

| | Coal | Crude oil | Natural gas | Petroleum products | Gas manufacture |
|---|---|---|---|---|---|
| Coal | 87.3 | 12.9 | 39.1 | 10.6 | 35.6 |
| Crude oil | 87.3 | 12.9 | 39.2 | 10.6 | 35.7 |
| Natural gas | 85.4 | 12.9 | 39.2 | 10.6 | 35.8 |
| Petroleum products | n.a. | n.a. | 39.2 | n.a. | 35.7 |
| Gas manufacture | 86.8 | 12.8 | n.a. | 10.6 | 35.8 |
| Electricity | 85.8 | 12.9 | 26.1 | 7.3 | 35.5 |
| Wood products | 87.4 | 13.0 | 37.6 | 9.8 | 35.4 |
| Chemical products | 87.6 | 13.0 | 3.0 | 6.9 | 35.4 |
| Mineral products | 84.9 | 13.0 | 22.0 | 9.8 | 35.2 |
| Metals | 85.0 | 12.9 | 24.6 | 9.8 | 35.0 |
| Metal products | 87.3 | 13.0 | 27.0 | 9.8 | 35.1 |
| Electronic equipment | 87.3 | 13.0 | 39.2 | 9.8 | 35.1 |
| Transports | 85.6 | 12.9 | 31.5 | 9.8 | 34.8 |
| Machinery equipment | 87.4 | 13.0 | 22.4 | 9.8 | 35.0 |
| Water | 71.1 | 12.7 | 39.1 | 9.8 | 34.4 |
| Agriculture | 84.1 | 12.9 | 23.9 | 9.8 | 35.2 |
| Food products | 86.8 | 13.0 | 37.2 | 9.8 | 35.2 |
| Construction | 87.4 | 12.9 | 39.0 | 9.8 | 35.2 |
| Trade products | 87.4 | 12.7 | 39.0 | 9.8 | 35.0 |
| Transport equipment | 87.9 | 13.0 | 39.0 | 10.6 | 35.6 |
| Private services | 60.8 | 12.9 | 29.1 | 9.8 | 32.7 |
| Public services | 53.0 | 12.9 | 23.6 | 9.8 | 31.1 |
| Minerals | 87.8 | 12.9 | 39.2 | 10.6 | 35.7 |
| Textiles | 87.4 | 12.9 | 38.9 | 10.6 | 35.0 |
| Paper products | 87.8 | 13.0 | 28.1 | 10.6 | 35.2 |
| Household | 52.2 | 12.5 | 38.8 | 8.0 | 35.3 |

Source: Own calculation based on Lee (2008) and Version 7 of the GTAP database.

$CO_2$ coefficients of coal, crude oil, and petroleum products used by the petroleum sector equal zero. The same assumption is made for natural gas used by gas manufacture. Coal has the largest $CO_2$ coefficient because of its high carbon intensity. While crude oil and petroleum products are more carbon intensive energy inputs compared to natural gas and gas manufacture, the $CO_2$ coefficients for crude oil and petroleum products are lower than those for gas. The reason for this is that the $CO_2$ coefficients are calculated at values, where domestic prices of gas have been quite low due to administrative regulation. Hence, relative increases in prices of energy inputs differ not only due to differences in carbon intensity, but also due to differences in the initial prices of energy (e.g. Hoeller and Wallin, 1991).

#### 6.1.2.3 Adjustment of Factor Demand by the Petroleum Sector

For some of the simulations, a Cournot oligopoly in markets for natural gas, metals, minerals, chemical products, and petroleum products is assumed. Cournot oligopoly is based on internal economies of scale due to fixed costs. Fixed costs are extracted from the labour and capital account. In other words, a part of labour and capital costs is assumed to be fixed costs, which do not vary with the production level. The petroleum product sector, however, has a quite small share of capital and labour costs. For example, the total factor cost of the petroleum sector does not exceed 10% of total production costs, as shown in Table 6.1. Therefore, 20% of capital and labour demand is moved from the oil sector to the petroleum sector, by using equations 6.1.1 to 6.1.4. Such adjustment of factor demand in the petroleum sector does not destroy the balance of the SAM.

---

$$SAM_{f,ap\_c} = SAM_{f,ap\_c} + 0.20 * SAM_{f,aoil} \tag{6.1.1}$$

$$SAM_{aoil,coil} = SAM_{aoil,coil} - \sum_{f} 0.20 * SAM_{f,aoil} \tag{6.1.2}$$

$$SAM_{coil,ap\_c} = SAM_{coil,ap\_c} - \sum_{f} 0.20 * SAM_{f,aoil} \tag{6.1.3}$$

$$SAM_{f,aoil} = (1 - 0.20) * SAM_{f,aoil} \tag{6.1.4}$$

---

The GTAP database distinguishes between two sectors namely “Oil” and “Petroleum, coal products” sector. The petroleum sector is the largest domestic consumer of crude oil, whose consumption share accounts for 90.9% of the total domestic demand for crude oil. Such adjustment of the database is justified from this point of view that the Russian oil sector is mainly represented by ten vertically integrated companies, which are dealing with extraction, processing, and transportation of crude oil and oil products.

#### 6.1.2.4 Extraction of Fixed Costs

Following Harris (1984) and Devarajan and Rodrik (1991) in order to incorporate a Cournot oligopoly with internal economies of scale, a part of capital and labour cost is assumed to be fixed. Therefore, additional accounts for fixed factors and taxes on fixed factors are incorporated into the SAM. Fixed costs and taxes on fixed factors are defined by equations (6.1.5) to (6.1.12). For example, equation (6.1.5) and (6.1.6) defines the total fixed costs ($SAM_{FCval,a}$) and taxes on fixed factors ($SAM_{FCtax,a}$), respectively, where $CDR_a$ is a cost disadvantage ratio that is assumed to equal 15%, $SAM_{Total,a}$ is total production costs, and $shval_a$ is the average tax on factor use.

**(6.1.5)** $$SAM_{FCval,a} = \frac{CDR_a * SAM_{Total,a}}{\left(1 + shval_a\right)}$$

**(6.1.6)** $$SAM_{FCtax,a} = shval_a * SAM_{FCval,a}$$

**(6.1.7)** $$shfix_a = \frac{SAM_{FCval,a}}{\sum\limits_{f\$fx_f} SAM_{f,a}}$$

**(6.1.8)** $$SAM_{hous,FCval} = \sum_{a\$irts_a} SAM_{FCval,a}$$

**(6.1.9)** $$SAM_{hous,f} = SAM_{hous,f} - \sum_{a\$irts_a} shfix_a * SAM_{f,a}$$

**(6.1.10)** $$SAM_{govt,FCtax} = \sum_{a} SAM_{FCtax,a}$$

**(6.1.11)** $$SAM_{govt,tff} = SAM_{govt,tff} - \sum_{a} shfix_a * SAM_{tff,a}$$

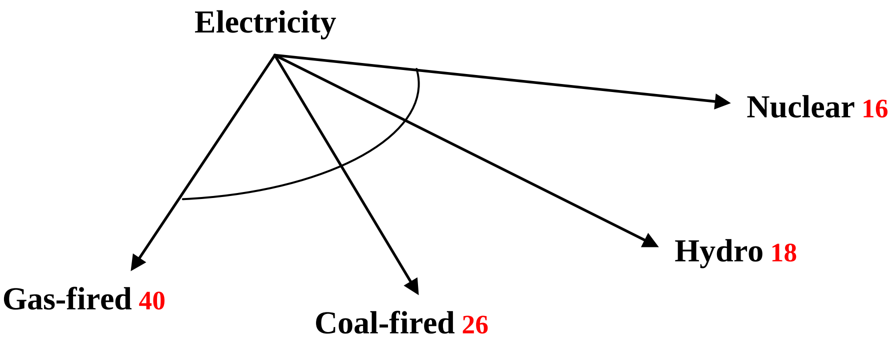
**(6.1.12)** $$SAM_{f,a} = SAM_{f,a} - shfix_a * SAM_{f,a}$$

The single household receives income from the fixed factor (equation 6.1.8), whereas the initial income from variable factors is reduced by the amount of fixed costs (equation 6.1.9). The government receives income from taxes on fixed factors (equation 6.1.10), while the initial income from taxes on variable factors is reduced by taxes on fixed factors (equation 6.1.11). Finally, factor demand of imperfectly competitive sectors is reduced by fixed costs, as given in equation 6.1.12.

#### 6.1.2.5 Disaggregation of the Power Generation Sector

As discussed in Section 5.4, thermal energy is the largest source of power generation, whose share accounts for 66% of total electricity generation in Russia (EIA, 2011a). The main fuel inputs of thermal energy generation are natural gas and coal. In 2009 the share of natural gas in the total demand for energy inputs amounted to 70.1%, followed by coal (27.8%), oil (2%), and other (0.1%) (EFA, 2009a). The SAM for Russia that is extracted from the GTAP database does not distinguish among different power generation technologies. Therefore, the electricity sector is disaggregated into four sectors, which represent the corresponding power generation technologies: gas-fired, coal-fired, hydro, and nuclear. Disaggregation of the power generation sector is based on output shares and coefficients of relative factor intensities. Output shares define how much energy is produced from a certain technology with respect to total power generation. For example, output from gas-fired technologies accounts for 40% of total power generation, coal-fired technologies (26%), hydro (18%), and nuclear (16%), as illustrated in Figure 6.1.

**Figure 6.1: Output Shares of Power Generation Technologies (per cent)**



Source: Own compilation.

Due to lack of information, all intermediate costs are distributed among technologies according to the output shares, i.e., the technologies are assumed to have the same intensity with respect to the use of intermediates. Energy inputs such as coal, crude oil, natural gas, gas manufacture and petroleum products are distributed through a certain technology. For example, gas-fired technologies require natural gas, gas manufacture and electricity for power generation. Coal-fired technologies require crude oil, coal, petroleum products, and electricity. Nuclear and hydro technologies require only electricity. Moreover, the electricity intensity is assumed to be the same among all power generation technologies, i.e., electricity costs are distributed among the technologies according the output shares. Power generation technologies differ with respect to their performance and factor intensity. For example as shown in Table 6.8, nuclear technologies are more capital intensive compared to coal-fired and gas-fired technologies.

**Table 6.8: Costs and Performance Data of Generation Technologies and $CO_2$ Emissions**

| | Capital (USD/kW) |
|---|---|
| **Coal CPP (USC)** | 2100 |
| **Nuclear** | 2600 |
| **Combined cycle CHP (gas)** | 1380 |

Source: Veselov et al. (2010).

To calculate the coefficients of relative capital intensity, capital cost per kW of nuclear technologies are divided by capital costs of each technology. Nuclear technology is selected as a reference technology because of the largest capital cost. Due to lack of information, it is assumed that labour intensity would be the same among all technologies. Moreover, the capital and labour intensity of hydro technologies is assumed to be the same as the capital and labour intensity of nuclear technologies. Table 6.9 shows the coefficients of relative factor intensity. For example, the coefficients of labour intensity equal unity among all technologies. The coefficient of capital intensity of coal-fired technologies equals 1.24 and for gas-fired technologies it is 1.88. This means that coal-fired and gas-fired technologies are by 24% and 88% less capital intensive compared to nuclear and hydro technologies. [29]

**Table 6.9: Coefficients of Relative Factor Intensity**

| Factors | Gas-fired | Coal-fired | Hydro | Nuclear |
|---|---|---|---|---|
| Unskilled Labour | 1.00 | 1.00 | 1.00 | 1.00 |
| Skilled Labour | 1.00 | 1.00 | 1.00 | 1.00 |
| Capital | 1.88 | 1.24 | 1.00 | 1.00 |

Source: Own compilation.

Using the output shares (Figure 6.1) and the coefficients of relative factor intensity (Table 6.9), the share parameters for distribution of factor costs are calculated as follows:

**(6.1.13)** $$kf(f,g)*\frac{shfd(f,g)}{shqx(g)} = kf(f,c)*\frac{shfd(f,c)}{shqx(c)} = kf(f,n)*\frac{shfd(f,n)}{shqx(n)} = kf(f,h)*\frac{shfd(f,h)}{shh(h)};$$

**(6.1.14)** $$shfd(f,g) + shfd(f,c) + shfd(f,n) + shfd(f,h) = 1;$$

where $shfd(f,*)$ are share parameters for distribution of factor costs among gas-fired, **c**oal, nuclear, and hydro power generation technologies;

$shqx(*)$ are output shares of gas-fired, coal-fired, nuclear, and hydro power generation technologies;

$kf(f,*)$ are coefficients of relative factor intensity among gas-fired, coal-fired, nuclear, and hydro power generation technologies;

Equation (6.1.13) equalizes the share parameters for distribution of factor costs ($shfd$), which are weighted by the output shares ($shqx$) and multiplied by the coefficients of relative factor intensity ($kf$). Equation (6.1.14) ensures that the sum over all share parameters ($shfd$) equals unity. These two equations can be solved either in GAMS or in Excel by using Solver command. Finally, the calculated share parameters ($shfd$) are used for calibration of the model with respect to the electricity sector. The share parameters are multiplied by production costs of the electricity sector to obtain production costs of a certain technology. Using this

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[29] Since the capital cost of nuclear technologies is divided by the capital cost of other technologies, the interpretation of coefficient of relative capital intensity is as follows. The larger is the coefficient of capital intensity, the less capital intensive is the technology.

approach, intermediate and factor costs are distributed among the power generation technologies, where the SAM remains balanced.

#### 6.1.2.6 Adjustment of the Export Tax Rate on Natural Gas

According to the GTAP database, the export tax rate on natural gas is approximately 82%, yet according to the Russian Tax Code, the export tax rate is only 30%. The problem is that introducing carbon taxes leads to an increase in export supply of natural gas, resulting in higher revenues from the export tax, such that the unrealistic value in the original GTAP database may distort the results. Therefore, the export tax rate is reduced from 82% to 30%. Table 6.10 shows how the SAM for Russia has been adjusted to achieve an export tax rate on natural gas equalling 30%.

**Table 6.10: Adjustment of the Export Tax Rate on Natural Gas**

| | Natural gas | Capital | Government | Export tax | ROW |
|---|---|---|---|---|---|
| Natural gas | | | | | (6.1.15) |
| Capital | | | (6.1.17) | | (6.1.16) |
| Government | | | | (6.1.18) | |
| Export tax | (6.1.19) | | | | |

Source: Own compilation.

**(6.1.15)** $SAM_{gas,row} = SAM_{gas,row} - adj * SAM_{\exp tax,gas}$

**(6.1.16)** $SAM_{kap,row} = SAM_{gas,row} + adj * SAM_{\exp tax,gas}$

**(6.1.17)** $SAM_{kap,govt} = SAM_{gas,row} - adj * SAM_{\exp tax,gas}$

**(6.1.18)** $SAM_{govt,\exp tax} = SAM_{gas,\exp tax} - adj * SAM_{\exp tax,gas}$

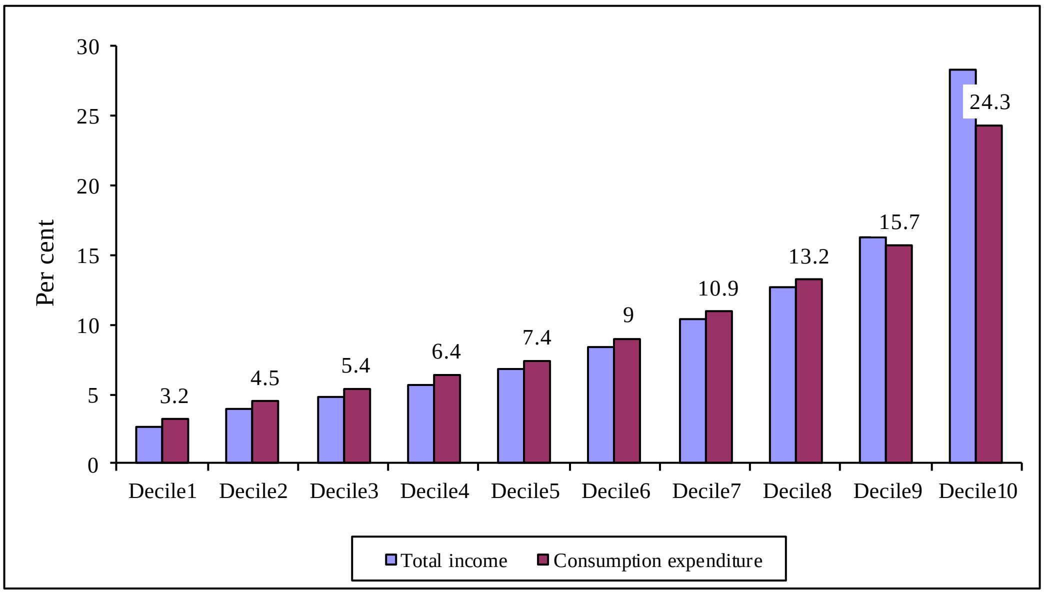
**(6.1.19)** $SAM_{\exp tax,gas} = SAM_{\exp tax,gas} - adj * SAM_{\exp tax,gas}$

where $adj$ is an adjustment parameter which is manually defined to achieve the export tax rate equalling 30%.

### 6.1.3 Estimation of Distributional Effects

The issue of income equity is of high relevance for Russia since income inequality is high: the Gini coefficient of income distribution was 0.42 in 2009 (FSSS, 2011). Our CGE analysis, however, is based on a database which includes only one representative household. To assess the impact of carbon taxes on income equity, a simple micro-accounting approach is used. Micro-data are taken from a Russian Household Budget Survey (FSSS, 2009) as well as Rutherford et al. (2005). Figure 6.2 illustrates the income and expenditure shares by ten deciles of overall income and consumption expenditure in 2009. For example, the poorest household group (decile1) spends 3.2% of overall consumption expenditure by all deciles, whereas for the richest household group (decile 10) the share is 24.3%.

**Figure 6.2: Shares of Income and Consumption Expenditure by Decile in Total in 2009 (per cent)**



Source: FSSS (2009).

Furthermore, the Russian Household Budget Survey (FSSS, 2009) provides also data on the expenditure shares on certain commodities consumed by decile. As shown in Table 6.11, the consumption share of food products and energy by poor household groups is larger compared to that by rich households. In contrast, rich households spend more on consumption of transport as well as electronic equipment and catering.

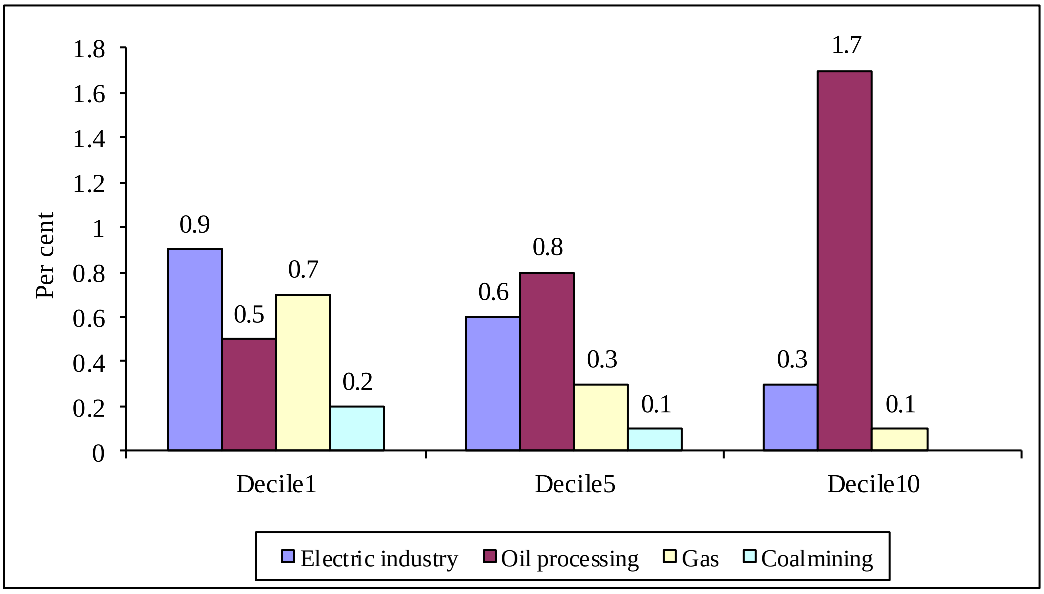
**Table 6.11: Household Consumption Shares by Deciles (per cent)**

| | Decile 1 | Decile 2 | Decile 3 | Decile 4 | Decile 5 | Decile 6 | Decile 7 | Decile 8 | Decile 9 | Decile 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Food products | 48.6 | 45.7 | 43.7 | 41.9 | 39.5 | 35.3 | 31.7 | 28.2 | 26.3 | 19.1 |
| Alcohol and tobacco | 2.6 | 2.5 | 2.6 | 2.6 | 2.6 | 2.7 | 2.4 | 2.3 | 2.5 | 2.0 |
| Textiles | 8.2 | 9 | 9.7 | 9.9 | 10.3 | 11.1 | 12.2 | 12.7 | 10.9 | 8.5 |
| Housing (reparation and keeping) | 0.6 | 0.8 | 0.9 | 1 | 1.5 | 1.5 | 1.6 | 2.1 | 2.7 | 2.9 |
| Water supply (service) and utilities | 5.6 | 5.1 | 4.7 | 4.3 | 3.9 | 3.4 | 2.9 | 2.5 | 2.2 | 1.8 |
| Electricity, gas and fuels | 10.0 | 9 | 8.4 | 7.7 | 7 | 5.8 | 4.9 | 4.1 | 3.9 | 2.8 |
| Electronic equipment, household goods | 2.9 | 3.5 | 4.1 | 4.5 | 5.2 | 6.7 | 6.6 | 8.1 | 10.7 | 7.4 |
| Health services | 2.2 | 2.4 | 2.6 | 2.7 | 2.9 | 3.6 | 3.4 | 3.1 | 3.5 | 2.8 |
| Transport equipment | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.3 | 0.8 | 1.5 | 3.3 | 20.7 |
| Exploitation of transport equipment | 1.5 | 2.3 | 2.7 | 3.4 | 3.8 | 4.5 | 4.7 | 5.4 | 5.1 | 4.6 |
| Transport services | 3.8 | 4 | 4.1 | 3.9 | 3.9 | 3.4 | 3.1 | 3 | 3 | 2.4 |
| Communication | 4.4 | 4.6 | 4.6 | 4.6 | 4.5 | 4.3 | 4.3 | 4.1 | 3.5 | 2.7 |
| Holidays and social events | 2.7 | 3.1 | 3.5 | 4.3 | 5 | 6.4 | 8.2 | 9 | 8.8 | 8.7 |
| Education | 0.6 | 1 | 1.3 | 1.5 | 1.7 | 2 | 2.3 | 2.3 | 1.6 | 0.8 |
| Catering | 0.9 | 1.2 | 1.3 | 1.4 | 1.7 | 2.4 | 3.2 | 3.4 | 4.3 | 5.3 |
| Other goods and services | 5.4 | 5.7 | 5.7 | 6.2 | 6.4 | 6.6 | 7.7 | 8.2 | 7.7 | 7.5 |
| **Total** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** |

Source: FSSS (2009).

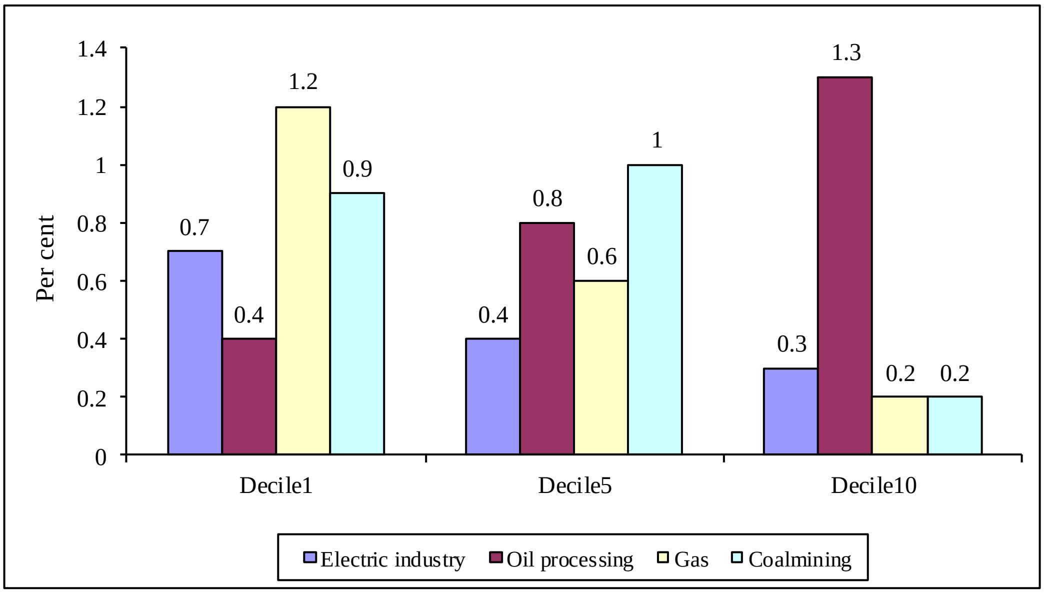
The Russian Household Budget Survey does not provide data on consumption shares of certain energy commodities consumed by households as well as factor income shares. Therefore, the estimated shares provided by Rutherford et al. (2005) are used. As shown in Figures 6.3 and 6.4, the consumption shares of coal, electricity and gas by poor households are larger compared to those by rich households. In contrast, rich household groups (decile 10) spend more on consumption of petroleum products relative to poor households. The intuitive explanation behind this is that poor households cannot afford a car so that they use more public transport.

**Figure 6.3: Shares of Consumption Expenditures by Urban Deciles (per cent)**



Source: Rutherford et al. (2005).

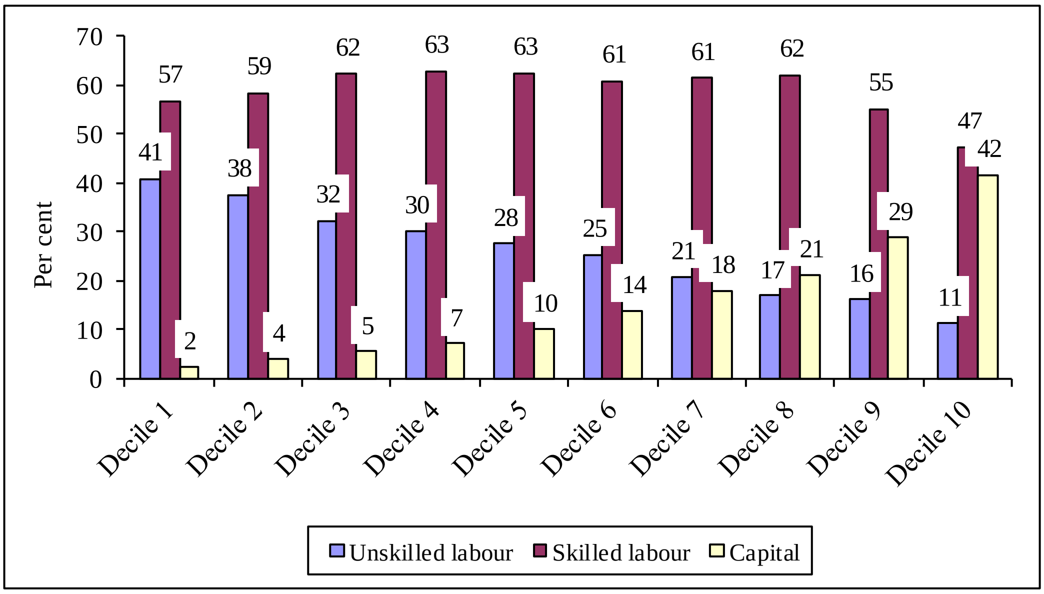
**Figure 6.4: Shares of Consumption Expenditures by Rural Deciles (per cent)**



Source: Rutherford et al. (2005).

Figure 6.5 illustrates the factor income shares by deciles. For example, the income share of unskilled labour by the poorest household group (decile 1) accounts for 41% of total factor income, whereas by the richest household group (decile 10) it is 11%. The main income source of all deciles is skilled labour, whose income share varies among household groups with being more pronounced by the middle-income household groups. The income share of capital is especially large for rich deciles: for example, 42% of total factor income of the richest household group comes from capital, whereas for the poorest household group capital accounts for only 2%.

**Figure 6.5: Factor Income Shares by Consumption Deciles (per cent)**



Source: Rutherford et al. (2004).[30]

Using factor income shares and consumption expenditures shares, factor income and consumption expenditures are distributed in the macro-data (SAM for Russia) among ten deciles, where each decile represents ten per cent of the population ranked according to income. Subsequently, factor income and consumption expenditure categories are multiplied by relative changes in factor and commodity prices, respectively, i.e. price changes are weighted by the base period composition of expenditures and factor income.[31]

## 6.2 Model Framework

In this study, the effects of carbon taxes on the Russian economy are analyzed by using a computable comparative static single-country multy-sector general equilibrium model. The use of CGE models has become one of the powerful tools to analyse policy implications since

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[30] Rutherford et al. (2004) provide also data on factor income shares by rural and urban households.

[31] Due to lack of information, changes in savings and lump-sum transfers are not taken into account.

this can cover different fields simultaneously: structural adjustment, international trade, public finance, income distribution, and energy and environmental policy (Devarajan and Robinson, 2002). CGE models are widely used for evaluation of environmental and energy related policies such as carbon leakage, carbon trading, and double dividend (Bergman, 2005). One of the main advantages of CGE models is that they allow capturing interrelations between product and factor markets. Indirect effects arising from factor markets can have a substantial impact on results (Parry and Oates, 2000). Moreover, using a general equilibrium model allows analysing effects of a tax policy in the presence of pre-existing distortions such as taxes and imperfect competition.

## 6.2.1 Numerical Model: Core Model

The model is a modified version of the comparative static “STAGE” model (McDonald, 2007). The STAGE model is a member of the class of computable-general equilibrium (CGE) models descended from the model described by Dervis et al. (1984) and more specifically the USDA ERS model (Robinson et al., 1990; and Kilkenny, 1991). The model is a Social Accounting Matrix (SAM) based single-country CGE model, which is implemented in General Algebraic Modelling System (GAMS) software.

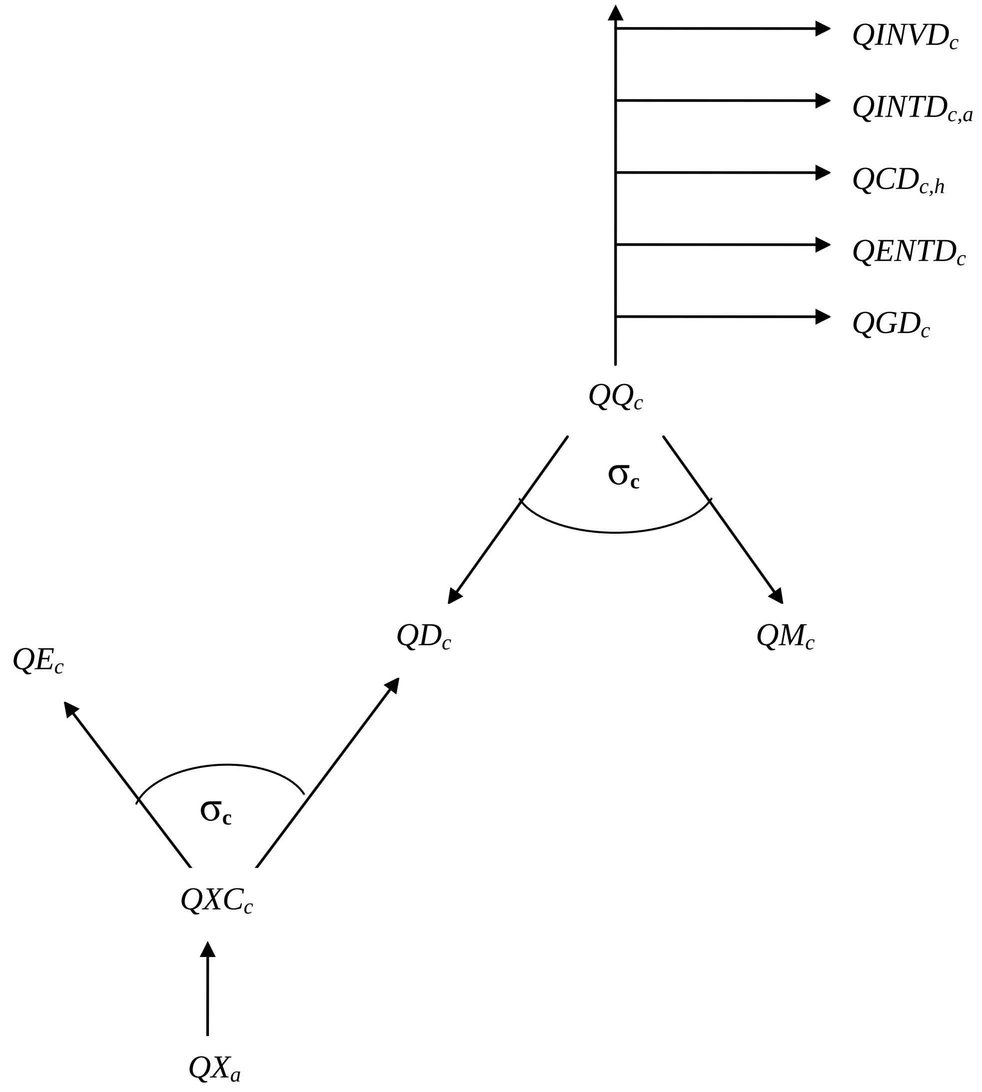
### 6.2.1.1 Quantity System

Figure 6.6 illustrates the quantity system in the standard version of the STAGE model. On the supply side, the domestically produced commodities ($QXC_c$) are distributed between export ($QE_c$) and domestic markets ($QD_c$) under the assumption of imperfect transformation. The imperfect transformation between export and domestic supply is described by a Constant Elasticity of Transformation (CET) function. Elasticities of transformation are introduced in Table 6.4. Furthermore, the country in question can also be modelled as a large economy with respect to certain markets, using an export demand function:

$$QE_c = econ_c * \left( \frac{PWE_c}{pwse_c} \right)^{-eta_c}, \qquad \forall c \in \text{ced(c)}$$

where *QE* is export demand, *econ* is a constant in the export demand, *PWE* is the world price of export from the rest of the world (ROW), *pswe* is the world price of export from the ROW, *eta* is elasticities of export demand, and *ced* is the sub-set for export commodities with an export demand function.

**Figure 6.6: Quantity System in the Standard Version of the STAGE Model**



Source: McDonald (2007).

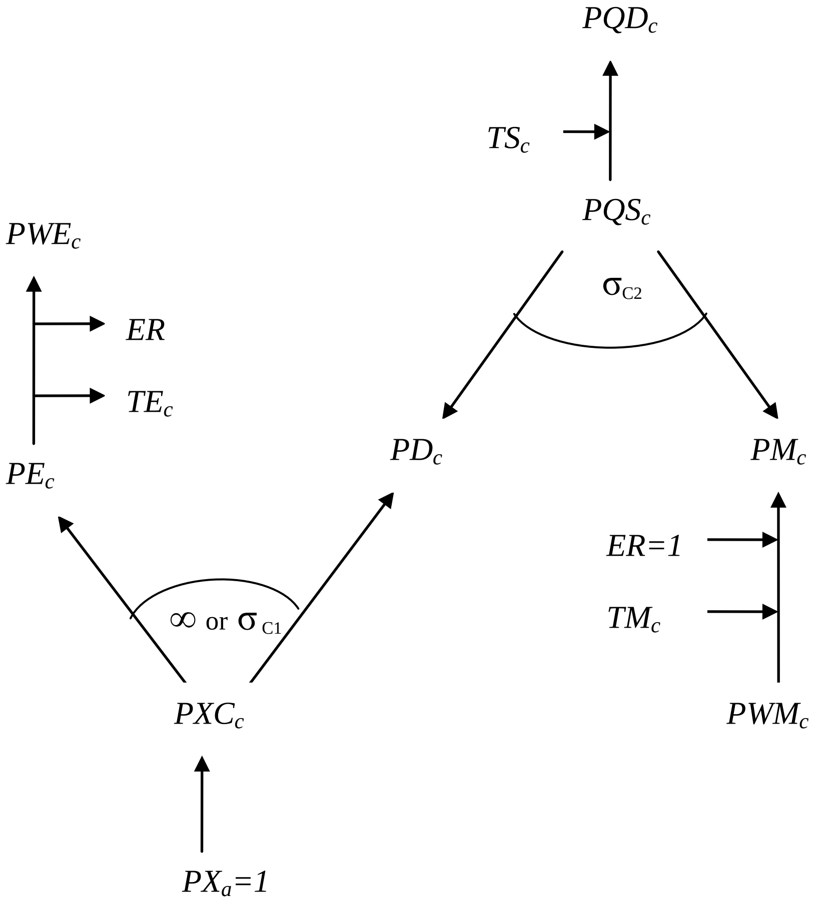
The composite commodities ($QQ_c$) are defined as the composites of the domestically produced commodities ($QD_c$) and the import commodities ($QM_c$) which are treated as imperfect substitutes. Hence, intra-industrial trade flows can be covered in the model. The imperfect substitution between imported and domestically produced commodities is incorporated according to the Armington approach (Armington, 1969), using a Constant Elasticity of Substitution (CES) function. Armington elasticities of substitution are presented in Table 6.4.

As shown in Figure 6.6 the demand side consists of five demand categories: investment demand ($QINVD_c$), intermediate demand ($QINTD_{c,a}$), private consumption demand ($QCD_c$), enterprises demand ($QENTD_c$) and government demand ($QGD_c$). Households maximise utility with their preferences being represented by a Stone-Geary utility function. The sources of investments are household, government, foreign savings and fiscal depreciation. Since our analysis is based on the GTAP database, there are no enterprises and all households are represented only by one single household.

#### 6.2.1.2 Price System

Figure 6.7 illustrates the price system in the standard version of the STAGE model. The supply prices of the composite commodities ($PQS_c$) are defined as the weighted averages of the prices of the domestically supplied commodities ($PD_c$) and the prices of the imported commodities ($PM_c$). At the same time, the prices of the imported commodities are specified as the world import prices ($PWM_c$), converted by the exchange rate ($ER$) plus the import tariff rates ($TM_c$).

**Figure 6.7: Commodity Price System in the Standard Version of the STAGE Model**



Source: McDonald (2007).

The prices of domestically produced commodities ($PXC_c$) are defined as the weighted averages of the producer prices of the domestically supplied commodities ($PD_c$) and the prices of the exported commodities ($PE_c$). The prices of the exported commodities are determined by the world export prices ($PWE_c$), converted by the exchange rate ($ER$) minus the export tariff rates ($TE_c$).

### 6.2.1.3 Calibration of the Commodity Price and Quantity System

By calibrating the standard version of the STAGE model, the initial values of almost all commodity prices are set to unity: $PD0_c = PE0_c = PM0_c = PQS0_c = PX0_a = PXC0_c = 1$. The calibration of the commodity quantity system is introduced in equations (6.2.1) to (6.2.7). By normalizing prices at unity, the quantities of total domestic production ($QX0$ and $QXC0$), export supply ($QE0$), domestic supply ($QD0$), import demand ($QM0$), and total domestic consumption ($QQ0$) equal the corresponding value in the SAM.

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**(6.2.1)** $$QX0_a = \frac{SAM_{total,a}}{PX0_a}$$

**(6.2.2)** $$QXC0_c = \frac{\sum_a SAM_{a,c}}{PXC0_c}$$

**(6.2.3)** $$QE0_c \frac{\left(SAM_{c,row} - SAM_{\exp tax,c}\right)}{PE_c}$$

**(6.2.4)** $$QD_c = \frac{\left(\sum_a SAM_{a,c} - (SAM_{c,row} - SAM_{\exp tax,c})\right)}{PD0_c}$$

**(6.2.5)** $$QM0_c \frac{(SAM_{row,c} + SAM_{imptax,c})}{PM0_c}$$

**(6.2.6)** $$QQ0_c = QD0_c + QM0_c$$

**(6.2.7)** $$PQD0_c \frac{(SAM_{c,total} - SAM_{c,row})}{QQ0_c}$$

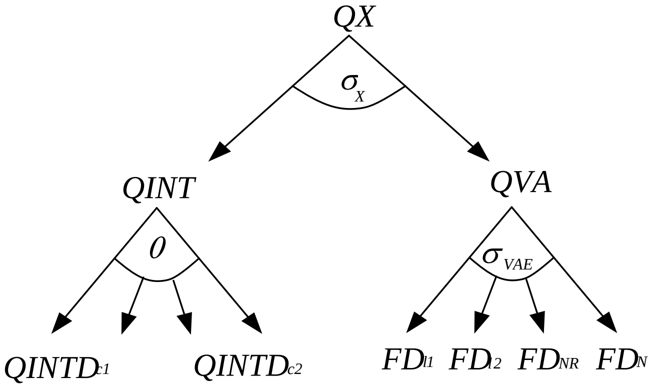
---

Source: McDonald (2007).

### 6.2.1.4 Production System

In the STAGE model all activities are assumed to maximise profits using two level nested production functions. Figure 6.8 illustrates the nesting structure in the standard version of the STAGE model. At the top level, the domestic output ($QX$) is defined by a two argument CES function over the aggregate of intermediates (*QINT*) and the aggregate of value added (*QVA*). On the second level, the aggregate of intermediates is described by a Leontief function, where the aggregate of value added (*QVA*) is a standard Constant Elasticity of Substitution (CES) function over primary factors.

**Figure 6.8: Nesting Structure in the Standard Version of the STAGE Model**



Source: McDonald (2007).

Most GTAP applications assume the nest at the top level of the production structure as zero. Setting the elasticity of substitution between intermediates and the value added aggregate different from zero is quite common for many other well established CGE models, such as IFPRI standard, MIRAGE, LINKAGE, and GLOBE. With a substantial change between the relative prices for intermediates compared to the value added-energy nest, which are simulated by introducing carbon taxes, there would be a substitution at this level in the long-run. Nevertheless, high substitution possibility between intermediates and the value added-energy aggregate is not expected: $\sigma_X$ is set to 0.5.

### 6.2.2 Numerical Model: Own Modifications

The design of the model is especially important where the policy experiment is implemented. With respect to our analysis, a more elaborated treatment of demand and supply of energy is required. Therefore, for this analysis the standard version of the STAGE model is modified as follows:

1) Incorporating factor-fuel as well as inter-fuel substitution for non-energy producing sectors.[32]

2) Incorporating a two level nested linear expenditure system for households, where the first level consists of energy and non-energy composites.

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[32] A factor-fuel substitution is a substitution between energy inputs and primary factors. An inter-fuel substitution is a substitution among energy inputs (Burniaux and Truong, 2002).

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

4) Incorporating imperfect competition and internal economies of scale into output markets for natural gas, metals, minerals, chemical products, and petroleum products.

5) Incorporating a labour supply function.

6) Modelling Russia as a large economy with respect to the natural gas market.

7) Incorporating the account of $CO_2$ emissions into the model.

The implemented modifications of the model are explained further below in more detail.

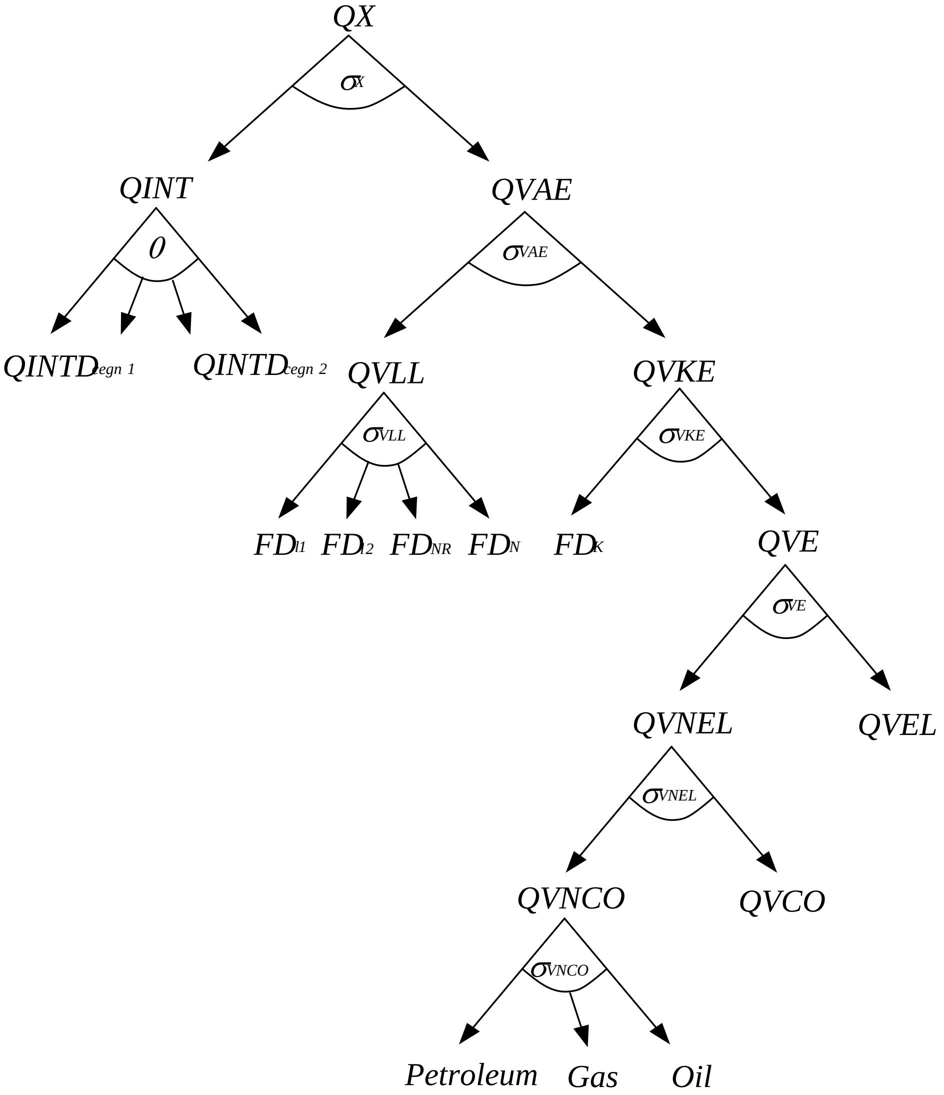
#### 6.2.2.1 Production System for Non-Energy Producing Sectors

According to Burniaux and Truong (2002), results significantly depend on substitution possibilities between energy and primary factors as well as substitution among energy inputs. Moreover, Sancho (2010), Capros et al. (1996) and Bovenberg and van der Ploeg (1998) assert that elasticities of substitution between capital, labour and energy are a crucial factor driving the results. Therefore, the standard version of the STAGE model is extended by incorporating substitution possibilities between capital and energy inputs as well as substitution possibilities among energy inputs for non-energy producing sectors. Introducing inter-fuel as well as factor-fuel substitution into the model is reasonable from theoretical and empirical point of view. The key factor is the values of elasticities of substitution between energy and primary factors as well as among energy inputs. The elasticities can differ by energy commodity and by sector as well as these can differ intertemporally (short and long term). To our knowledge, there are no estimations on elasticities of factor-fuel and inter-fuel substitution for Russia. Therefore, elasticities used in the GTAP energy model are taken (see Table 6.4).

The equation block for nesting structures is built using a dual approach. According to the dual approach, a unit cost function (or price index) is derived from a production function by minimization of production cost subject to a given production level, whereas demand functions 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 corresponding macro functions are listed in Appendix B. Figure 6.9

illustrates the modified nesting structure of non-energy producing sectors which consists of six levels. Nested CES functions are used. The nesting structure for non-energy producing sectors is similar to that implemented in the GTAP energy model (Burniaux and Truong, 2002). The only difference is that substitution possibilities between the intermediates (*QINT*) and the value added-energy aggregate (*QVAE*) are allowed in the model.

**Figure 6.9: Modified Nesting Structure for Non-Energy Producing Sectors**



Source: Own compilation.

For introduction of energy substitution, energy inputs such as natural gas, gas manufacture, coal, crude oil, petroleum products, and electricity are moved from intermediates (*QINT*) to the value added aggregate (*QVA*). The sub-set $gtap_a$ and $leon_a$ are used to assign sectors to a corresponding nesting structure. For example, the sub-set $gtap_a$ includes all non-energy producing sectors, whereas the sub-set $leon_a$ includes energy sectors such as coal, crude oil, petroleum production, natural gas. Using the sub-set $nely_a$, the electricity sector is excluded from $gtap_a$ and $leon_a$ nesting structures since the electricity sector is modelled using a technology bundle approach.

**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-energy ($QVAE_a$). Equation (6.2.8) determines the unit cost function for the activity price of total production ($PX_a$), where $TX_a$ is a production tax. Equations (6.2.9) and (6.2.10) define the corresponding demand functions for $QVAE_a$ and $QINT_a$, respectively.

**Production Block – Top Level**

**(6.2.8)** $PX_a * (1 - TX_a) = px\_ces_a$ $\quad \forall a \in \text{nely}_\text{a}$

**(6.2.9)** $QVAE_a = qvae\_ces_a$ $\quad \forall a \in \text{nely}_\text{a}$

**(6.2.10)** $QINT_a = q\text{int}\_ces_a$ $\quad \forall a \in \text{nely}_\text{a}$

**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 (6.2.11) determines the unit cost function for the activity price of the value added-energy aggregate ($PVAE_a$). Equations (6.2.12) and (6.2.13) 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 Table 6.4).

**Production Block – Second Level**

**(6.2.11)** $PVAE_a = pvae\_ces_a$ $\quad \forall a \in \text{nely}_\text{a}$

**(6.2.12)** $QVKE_a = qvke\_ces_a$ $\quad \forall a \in \text{nely}_\text{a}$

**(6.2.13)** $QVLL_a = qvll\_ces_a$ $\quad \forall a \in \text{nely}_\text{a}$

**Third level.** The aggregate of primary factors ($QVLL_a$) is determined by a standard CES function over land, natural resources, skilled, and unskilled labour ($FD_{f,a}$). Land is used only by the agriculture sector, whereas natural resources are used by agriculture, coal, crude oil, natural gas, and minerals. Equation (6.2.14) determines the unit cost function for the activity price of the primary factors aggregate ($PVLL_a$). Equation (6.2.15) 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 Table 6.4).

The aggregate of capital-energy ($QVKE_a$) is depicted by a two argument CES function over the aggregate of energy inputs ($QVE_a$) and capital ($FD_{fCap,a}$). Equation (6.2.16) determines the cost unit function for the activity price of capital-energy aggregate ($PVKE_a$). Equations (6.2.17) and (6.2.18) 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

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**(6.2.14)** $PVLL_a = pvll\_ces_a$ $\forall a \in nely_a$ and $\forall a \in gtap_a$

**(6.2.15)** $FD_{f,a} = fd\_ces_{f,a}$ $\forall a \in nely_a$ and $\forall a \in gtap_a$ and $\forall a \in capn_f$

**(6.2.16)** $PVKE_a = pvke\_ces_a$ $\forall a \in nely_a$ and $\forall a \in gtap_a$

**(6.2.17)** $QVE_a = qve\_ces_a$ $\forall a \in nely_a$ and $\forall a \in gtap_a$

**(6.2.18)** $FD_{fCap,a} = fdcap\_ces_{fCap,a}$ $\forall a \in nely_a$ and $\forall a \in gtap_a$

where *capn* is the sub set for production factors, excluding capital.

---

**Fourth level.** The aggregate of energy inputs ($QVE_a$) is specified as a Cobb-Douglas function over the aggregate of non-electric energy commodities ($QVNEL_a$) and electricity ($QVEL_a$). Equation (6.2.19) defines the unit cost function for the activity price of the energy aggregate ($PVE_a$). Equations (6.2.20) and (6.2.21) determine the corresponding demand functions for $QVEL_a$ and $QVNEL_a$, respectively. Equation (6.2.22) gives the quantity identity for electricity demand ($QVEL_a$), whereas equation (6.2.23) defines the price identity for electricity ($PVEL_a$).

**Production Block for Non-Energy Producing Sectors – Fourth Level**

**(6.2.19)** $PVE_a = pve\_cd_a$ $\forall$ a $\in$ $\text{nely}_a$ and $\forall$ a $\in$ $\text{gtap}_a$

**(6.2.20)** $QVEL_a = qvel\_cd_a$ $\forall$ a $\in$ $\text{nely}_a$ and $\forall$ a $\in$ $\text{gtap}_a$

**(6.2.21)** $QVNEL_a = qvnel\_cd_a$ $\forall$ a $\in$ $\text{nely}_a$ and $\forall$ a $\in$ $\text{gtap}_a$

**(6.2.22)** $QVEL_a = QINTD_{cely,a}$ $\forall$ a $\in$ $\text{nely}_a$ and $\forall$ a $\in$ $\text{gtap}_a$

**(6.2.23)** $PVEL_a = PQD_{cely}$ $\forall$ a $\in$ $\text{nely}_a$ and $\forall$ a $\in$ $\text{gtap}_a$

where $QVEL_a$ and $QINTD_{cely,a}$ is demand for electricity by industries;
$PVEL_a$ and $PQD_{cely}$ is the consumer price of electricity.

**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 (6.2.24) determines the unit cost function for the activity price of the non-electric aggregate ($PVNEL_a$). Equations (6.2.25) and (6.2.26) define the corresponding demand functions for $QVCO_a$ and $QVNCO_a$, respectively. Equations (6.2.27) and (6.2.28) define 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 the GTAP energy model (Burniaux and Truong, 2002).

**Production Block for Non-Energy Producing Sectors – Fifth Level**

**(6.2.24)** $PVNEL_a = pvnel\_ces_a$ $\forall$ a $\in$ $\text{nely}_a$ and $\forall$ a $\in$ $\text{gtap}_a$

**(6.2.25)** $QVCO_a = qvcon\_ces_a$ $\forall$ a $\in$ $\text{nely}_a$ and $\forall$ a $\in$ $\text{gtap}_a$

**(6.2.26)** $QVNCO_a = qvnvo\_ces_a$ $\forall$ a $\in$ $\text{nely}_a$ and $\forall$ a $\in$ $\text{gtap}_a$

**(6.2.27)** $QVCO_a = QINTD_{ccoa,a}$ $\forall$ a $\in$ $\text{nely}_a$ and $\forall$ a $\in$ $\text{gtap}_a$

**(6.2.28)** $PVCO_a = PQD_{ccoa} + TCARB_{ccoa,a}$ $\forall$ a $\in$ $\text{nely}_a$ and $\forall$ a $\in$ $\text{gtap}_a$

**Sixth level.** Finally, the aggregate of non-coal energy commodities ($QVNCO_a$) is specified as a Cobb-Douglas function over natural gas, gas manufacture, crude oil, and petroleum products ($QINTD_{c,a}$). Equation (6.2.29) determines the unit cost function for the activity price of the non-coal aggregates (*$PVNCO_a$*). Equation (6.2.30) defines the corresponding demand function for natural gas, gas manufacture, crude oil, and petroleum products.

**Production Block for Non-Energy Producing Sectors – Sixth Level**

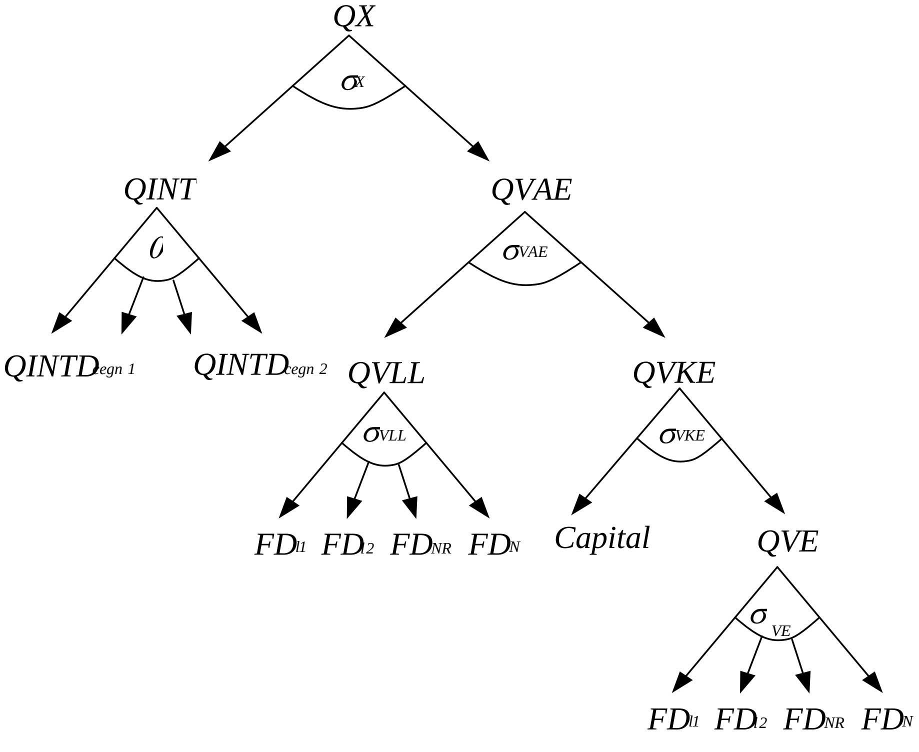
**(6.2.29)** $PVNCO_a = pvnco\_cd_a$ $\forall a \in nely_a$ and $\forall a \in gtap_a$

**(6.2.30)** $QINTD_{c,a} = q\mathrm{int}d\_cd_{c,a}$ $\forall a \in nely_a$ and $\forall a \in gtap_a$

### 6.2.2.2 Production System for Energy Producing Sectors

Following Burniaux and Truong (2002), the energy producing sectors, such as crude oil, coal, natural gas, and petroleum products are assumed to have no substitution possibilities between capital and energy inputs as well as among energy inputs so that one limits elasticities of energy supply. Figure 6.10 illustrates the nesting structure of energy producing sectors.

**Figure 6.10: Nesting Structure of Energy Producing Sectors**



Source: Own compilation.

**Third level.** 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. Equation (6.2.31) determines the unit cost function for the activity price of the capital-energy aggregate

($PVKE_a$), where equations (6.2.32) and (6.2.33) are the corresponding demand functions for $QVE_a$ and $FD_{fCap,a}$., respectively.

**Production Block for Energy Producing Sectors – Third Level**

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**(6.2.31)** $$PVKE_a = pvke\_leon_a \qquad \forall a \in \text{nely}_a \text{ and } \forall a \in \text{leon}_a$$

**(6.2.32)** $$QVE_a = qve\_leon_a \qquad \forall a \in \text{nely}_a \text{ and } \forall a \in \text{leon}_a$$

**(6.2.33)** $$FD_{fCap,a} = fdcap\_leon_{fCap,a} \qquad \forall a \in \text{nely}_a \text{ and } \forall a \in \text{leon}_a$$

---

**Fourth level.** The aggregate of energy inputs ($QVE_a$) for energy producing sectors is determined by a Leontief function. Equation (6.2.34) determines the unit cost function for the activity price of the energy aggregate ($PVE_a$), where equation (6.2.35) gives the corresponding demand functions for energy inputs ($QINTD_{c,a}$).

**Production Block for Energy Producing Sectors – Fourth Level**

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**(6.2.34)** $$PVE_a = pve\_leon_a \qquad \forall a \in \text{nely}_a \text{ and } \forall a \in \text{leon}_a$$

**(6.2.35)** $$QINTD_{c,a} = q\operatorname{int}d\_leon_{c,a} \qquad \forall a \in \text{nely}_a \text{ and } \forall a \in \text{leon}_a \text{ and } \forall c \in \text{ceg}_c$$

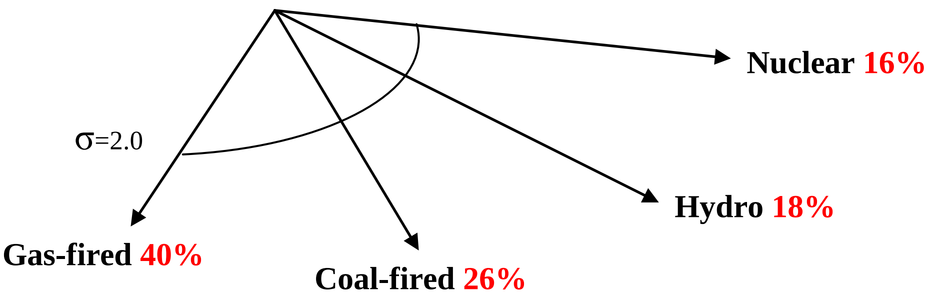
---

This nesting structure is also used for non-energy producing sectors to assess the implication of carbon taxes under different nesting structures.

#### 6.2.2.3 Modelling the Power Generation Sector

The power generation sector is the largest domestic consumer of coal and gas as well as a large domestic consumer of petroleum products. An explicit design of the power generation sector is expected to be crucial. The electricity generation sector is disaggregated into four power generation technologies: coal-fired, gas-fired, nuclear technologies and hydro technologies (Figure 6.11). The disaggregation is based on output shares and factor intensities by technologies, as discussed in Section 6.1.2.5. For example, gas-fired technologies produce 40% of total electricity generation, followed by coal-fired technologies (26%), hydro (18%), and nuclear (16%) (EIA, 2011a; 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).

**Figure 6.11: Structure of the Power Generation Sector**



Source: Own compilation.

The modelling of electricity generation technologies is based on a technology bundle approach similar to that is applied in the MEGABARE model (ABARE, 1996). According to this approach, all power generation technologies are substitutes for each other. Substitution among technologies is depicted by using a standard CES function. In the MEGABARE model, however, electricity technologies are modelled using a CRESH function. It is necessary to introduce a CES or CRESH function within the power generation technologies in a comparative static CGE model to avoid an unrealistic large switch from one technology to another. Due to lack of information, a standard one level CES function is used, where the elasticity of substitution among technologies is assumed to equal 2.0. Furthermore, in the MEGABARE model each technology is described by a Leontief function, which implies no substitution among primary factors and intermediates. In contrast, some substitution possibility within the production structure of all technologies is assumed.

Equation (6.2.36) defines the unit cost function for the activity price of electricity ($PX_a$), where $TX_a$ is a production tax on electricity. Equation (6.2.37) represents the corresponding demand function for output from different electricity generation technologies ($QXtb_{a,tb}$). The macro functions are listed in Annex B.

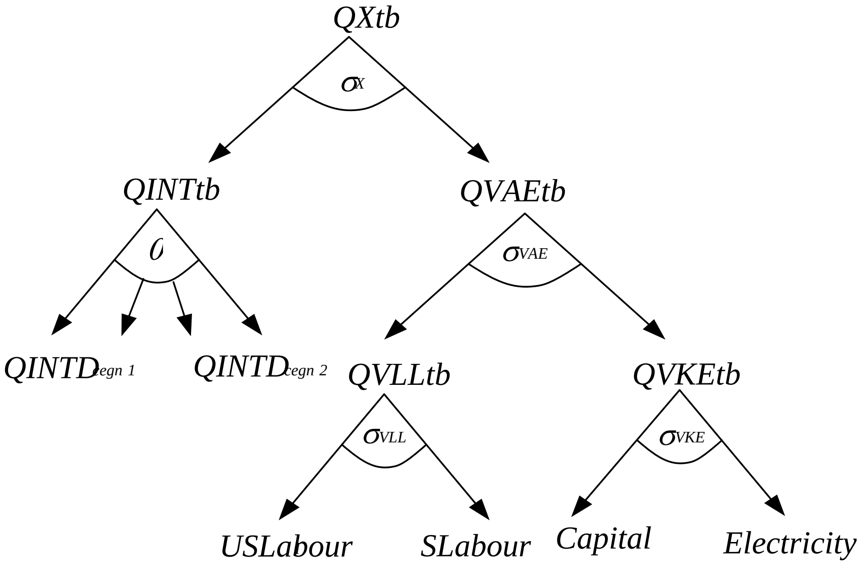
**Technology Bundle for the Power Generation Sector**

**(6.2.36)** $$PX_a * (1 - TX_a) = pxe\_ces_a \qquad \forall a \in \mathrm{ely}_a$$

**(6.2.37)** $$QXtb_{a,tb} = qxtb\_ces_{a,tb} \qquad \forall a \in \mathrm{ely}_a$$

Each power generation technology is described by a nested production structure, which is similar to the nesting structure applied for non-energy producing sectors (Figure 6.12). The same elasticities of substitution among primary factors are used as those are used for non-energy producing sectors. In addition, to make the nesting structure of electricity generation technologies comparable with others, the letters *tb* are added to the notations of prices and quantities, where *tb* states for technology bundle. For example, $QINT_a$ is an aggregate of intermediates used by non-electricity sectors, whereas $QINTtb_{a,tb}$ is an aggregate of intermediates used by the electricity sector namely by power generation technologies. Figure 6.12 illustrates the nesting structure for nuclear and hydro generation technologies.

**Figure 6.12: Nesting Structure for Nuclear and Hydro Generation Technologies**



Source: Own compilation.

**Top level.** 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 (6.2.38) determines the unit cost function for the activity price for electricity technologies (*PXtb*), where equations (6.2.39) and (6.2.40) are the corresponding demand functions for *QVAEtb* and *QINTtb*, respectively. Equation (6.2.41) defines the price identity for intermediate prices for electricity technologies. The sub-set $ely_a$ defines that the only electricity sector is modelled by using technology bundle approach.

### Production Block for Electricity Technologies – Top Level

**(6.2.38)** $PXtb_{a,tb} = pxtb\_ces_{a,tb}$ $\forall a \in \mathrm{ely}_a$

**(6.2.39)** $QVAEtb_{a,tb} = qvaetb\_ces_{a,tb}$ $\forall a \in \mathrm{ely}_a$

**(6.2.40)** $QINTtb_{a,tb} = q\,\mathrm{int}\,tb\_ces_{a,tb}$ $\forall a \in \mathrm{ely}_a$

**(6.2.41)** $PINTtb_{a,tb} = PINT_a$ $\forall a \in \mathrm{ely}_a$

**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 (6.2.42) determines the unit cost function for the activity price of the value added-energy aggregate (*PVAEtb*), where equations (6.2.43) and (6.2.44) are the corresponding demand functions *QVLLtb* and *QVKEtb*, respectively.

### Production Block for Electricity Technologies – Second Level

**(6.2.42)** $PVAEtb_{a,tb} = pvaetb\_ces_{a,tb}$ $\forall a \in \mathrm{ely}_a$

**(6.2.43)** $QVLLtb_{a,tb} = qvlltb\_ces_{a,tb}$ $\forall a \in \mathrm{ely}_a$

**(6.2.44)** $QVKEtb_{a,tb} = qvketb\_ces_{a,tb}$ $\forall a \in \mathrm{ely}_a$

**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 agriculture, coal, crude oil, natural gas, and minerals. Equation (6.2.45) determines the unit cost function for the activity price of the labour aggregate (*PVLLtb*), where equation (6.2.46) defines the corresponding demand function for *FDtb*.

### Production Block for Electricity Technologies – Third Level

**(6.2.45)** $PVLLtb_{a,tb} = pvlltb\_ces_{a,tb}$ $\forall a \in \mathrm{ely}_a$

**(6.2.46)** $FDtb_{f,a,tb} = fdtb\_ces_{f,a,tb}$ $\forall a \in \mathrm{ely}_a$

The aggregate of capital-energy (*QVKEtb*) is determined as a two argument CES function over capital ($FDtb_{Cap}$) and the energy aggregate (*QVEtb*), where the energy aggregate for hydro and nuclear technologies are represented by electricity only. Equation (6.2.47) determines the unit cost function for the activity price of the capital-energy aggregate (*PVKEtb*), where equations (6.2.48) and (6.2.49) define the corresponding demand functions for $FDtb_{\mathrm{Cap}}$ and *QVEtb*, respectively. For hydro and nuclear technologies, equations (6.2.50) and (6.2.51) represent the quantity and price identity of demand for electricity by the technologies.

**Production Block for Electricity Technologies – Third Level**

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**(6.2.47)** $PVKEtb_{a,tb} = pvketb\_ces_{a,tb}$ $\quad \forall a \in \mathrm{ely}_a$

**(6.2.48)** $FDtb_{fCap,a,tb} = fdtbke\_ces_{fCap,a,tb}$ $\quad \forall a \in \mathrm{ely}_a$

**(6.2.49)** $QVEtb_{a,tb} = qvetb\_ces_{a,tb}$ $\quad \forall a \in \mathrm{ely}_a$

**(6.2.50)** $QVEtb_{a,tb} = QINTDtb_{cely,a,tb}$ $\quad \forall a \in \mathrm{ely}_a$ and $c \in \mathrm{ceg}_c$ and $tb \in \mathrm{thern}_{tb}$

**(6.2.51)** $PVEtb_{a,tb} = PQD_{cely}$ $\quad \forall a \in \mathrm{ely}_a$ and $tb \in \mathrm{thern}_{tb}$

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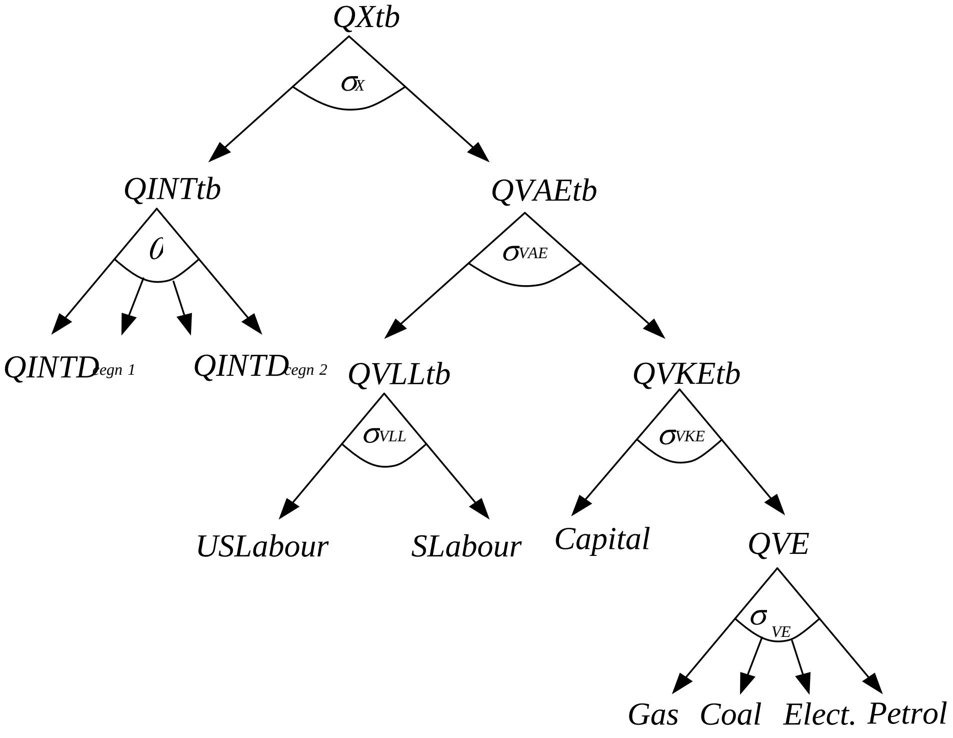
For coal-fired and gas-fired technologies, the production structure consists of four levels, where the last level represents an aggregate of energy inputs (*QVEtb*). Figure 6.13 shows the production structure of gas- and coal-fired power generation technologies.

**Figure 6.13: Nesting Structure for Gas-Fired and Coal-Fired Power Generation Technologies**



Source: Own compilation.

**Fourth level.** Within gas-fired technologies, the energy aggregate (*QVEtb*) is specified as a standard CES function over natural gas, gas manufacture, and electricity (*QINTDtb*). For coal-fired technologies, this is a standard CES function over coal, crude oil, petroleum products, and electricity (*QINTDtb*). Equation (6.2.52) determines the unit cost function for the activity price of the energy aggregate (*PVEtb*), where equation (6.2.53) specifies the corresponding demand functions for energy inputs used by thermal technologies.

**Production Block for Coal-and Gas-Fired Technologies – Fourth Level**

**(6.2.52)** $PVEtb_{a,tb} = pvetb\_ces_{a,tb}$ $\forall a \in \text{ely}_a$

**(6.2.53)** $QINTDtb_{c,a,tb} = q\,\text{int}\,dtb\_ces_{c,a,tb}$ $\forall a \in \text{ely}_a$

Equations (6.2.54), (6.2.55) and (6.2.56) 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**

**(6.2.54)** $FD_{f,a} = \sum_{tb} FDtb_{f,a,tb}$ $\forall a \in \text{ely}_a$

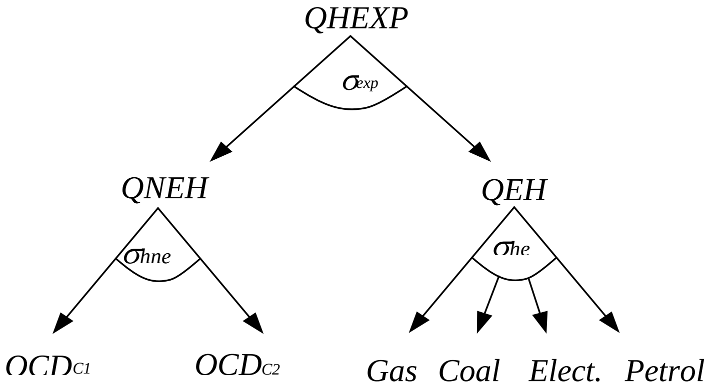
**(6.2.55)** $QINT_a = \sum_{tb} QINTtb_{a,tb}$ $\forall a \in \text{ely}_a$

**(6.2.56)** $QINTD_{c,a} = \sum_{tb} QINTDtb_{c,a,tb}$ $\forall a \in \text{ely}_a$

### 6.2.2.4 Structure of Household Demand

In the standard STAGE model, the household demand functions are derived from a Stone-Geary utility function. The main features of such 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 curve. For our analysis, a nested linear expenditure demand system for household consumption is introduced, which is similar to the government demand system applied in the GTAP energy model (Burniaux and Truong, 2002). Figure 6.14 illustrates the household demand system in the modified version of the STAGE model.

**Figure 6.14: Household Demand System**



Source: Own compilation.

**Top level.** 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 function is derived using a dual approach. Macro functions are used to model price indices and corresponding demand functions. Equation (6.2.57) determines the price index for the total household consumption ($PHEXP_h$). Equation (6.2.58) and (6.2.59) represents the corresponding demand functions for the energy composite ($QEH_h$) and the non-energy composite ($QNEH_h$).

**Household Consumption: Top Level**

**(6.2.57)** $$PHEXP_h = ph\exp\_ces_h$$

**(6.2.58)** $$QEH_h = qeh\_ces_h$$

**(6.2.59)** $$QNEH_h = qneh\_ces_h$$

**Second level.** The composite of energy commodities ($QEH_h$) is a Cobb-Douglas function over natural gas, gas manufacture, coal, petroleum products, and electricity, whereas the consumption of crude oil is not recorded. Equation (6.2.60) determines the price index of the energy composite ($PEH_h$), where equation (6.2.61) defines the corresponding demand function for energy commodities ($QCDhe_{c,h}$).

**Household Consumption: Second Level**

**(6.2.60)** $PEH_h = qeh\_cd_h$

**(6.2.61)** $QCDhe_{c,h} = qcd\_cd_{c,h} \quad \forall c \in \text{he}_\text{c}$

**(6.2.62)** $PNEH_h = qneh\_cd_h$

**(6.2.63)** $QCDhne_{c,h} = qcd\_cd_{c,h} \quad \forall c \in \text{hne}_\text{c}$

**(6.2.64)** $QHEXP_h * PHEXP_h = HEXP_h - \sum_c qcdconst_{c,h} * (PQD_c + TCARBH_{c,h})$

**(6.2.65)** $QCD_{c,h} = qcdconst_{c,h} + QCDhe_{c,h} \quad \forall c \in \text{he}_\text{c}$

**(6.2.66)** $QCD_{c,h} = qcdconst_{c,h} + QCDhne_{c,h} \quad \forall c \in \text{hne}_\text{c}$

The composite of non-energy commodities ($QNEH_h$) is also determined by a Cobb-Douglas function over non-energy commodities. Demand functions for energy and non-energy commodities consumed by the household are differentiated using a sub-set $he_c$ and $hne_c$, respectively. Equation (6.2.62) defines the price index of the non-energy composite ($PNEH_h$), where equation (6.2.63) specifies the corresponding demand function for non-energy commodities ($QCDhne_{c,h}$). Equation (6.2.64) represents the income balance for household consumption. Equation (6.2.65) and (6.2.66) determine the total household consumption, which consists of the subsistence consumption ($qcdconst_{c,h}$) and the superior consumption of the energy ($QCDhe_{c,h}$) and non-energy composites ($QCDhne_{c,h}$). Due to lack of information, income elasticities are assumed to equal unity so that subsistence consumption equals zero.

### 6.2.2.5 Cournot Oligopoly in Domestic Markets

In any real economy, many markets can be characterized as being imperfectly competitive. For example, many resource-based sectors require high investments in plants and equipment and, therefore, exhibit decreasing average costs. Usually such sectors consist of a small number of firms (Devarajan and Rodrik, 1991). The Russian economy strongly depends on resource-based sectors, such as natural gas, crude oil, minerals, and metals.

Compared to other sectors, as shown in Table 6.12, extraction of energy resources, extraction of mineral resources, petroleum products, chemical products, mineral products, and metals exhibit the highest rates of return on sales (ROS).[33] For example, the highest ROS is achieved by the extraction of mineral resources sector, which ROS was 49.2% in 2008. In contrast, the ROS of sectors such as transport and communication and real estate services (leasing) equalled 14.2% and 12.2% in 2008, respectively, and the ROS of other sectors does not exceed 11%.

**Table 6.12: Sectoral Rates of Return on Sales and the Number of Firms from 2005 to 2008 (ROS in per cent)**

| | | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|
| Extraction of energy resources | ROS | 34.7 | 29.2 | 30.1 | 22.6 |
| | Number of firms | 89 | 47 | 53 | 54 |
| Extraction of mineral resources (non-energy) | ROS | 42.8 | 42.4 | 33.3 | 49.2 |
| | Number of firms | 45 | 43 | 33 | 30 |
| Petroleum products | ROS | 21.4 | 21.1 | 27.5 | 27.8 |
| | Number of firms | 7 | 7 | 6 | n.a |
| Chemical products | ROS | 19.3 | 16.5 | 19.0 | 29.9 |
| | Number of firms | 32 | 27 | 28 | 22 |
| Minerals nec | ROS | 12.3 | 19.3 | 28.5 | 22.4 |
| | Number of firms | 94 | 86 | 84 | 69 |
| Metals | ROS | 30.1 | 39.2 | 33.6 | 28.7 |
| | Number of firms | 91 | 85 | 82 | 57 |

**nec** states for nevertheless classified

Sources: FSSS (2009).

High profitability is not necessarily an indicator of market power since high profitability can result from high productivity of primary factors. Therefore, another important aspect is the market concentration. As shown in Table 6.12, the number of firms is relatively small in sectors with the highest ROS. For example, the petroleum products sector consisted of six firms in 2007, the chemical products sector consisted of 22 firms in 2007, and the extraction of non-energy mineral resources sector consisted of 30 firms in 2008. In contrast, the extraction of energy resources sector which includes sub-sectors such as crude oil, coal, and natural gas, consisted of 54 firms in 2008. The metals and metal products sector consisted of 57 firms and the mineral products *nec* sector consisted of 69 firms in 2008. The number of firms has been changing in each sector. This could result from new small firms entering the market or from consolidation of already existing firms. Also, the number of firms is a limited indicator of market power. For example, a market can consist of a large number of firms, yet a few large companies may hold market power.

Since imported and domestically produced commodities are treated as imperfect substitutes, domestic firms can exploit some market power in the domestic market (Devarajan and

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[33] Rate of Return on Sales (ROS) is calculated by dividing the firm's accounting profit by sale revenues

Rodrik, 1991). Therefore, and due to the small number of firms and high profitability, an oligopolistic structure in sectors such as petroleum products, chemical products, metals, minerals, and mineral products is assumed. For example, domestic prices of petroleum products in Russia are subject to regular inspections, which are performed by the Russian Federal Antimonopoly Service. This is done because prices of petroleum products are "too high" and often raise suspicion in terms of oligopolistic behaviour by oil companies (FAS, 2009). Imperfect competition in these markets is assumed to be based on internal economies of scale.

The natural gas market in Russia is also treated as an imperfectly competitive market. Nevertheless, because of administrative price regulation, Russian gas producers (mainly Gazprom) do not have any market power in the domestic market, yet they are expected to exploit some market power in the world gas market (Tarr and Thomson, 2004). Average-cost pricing for natural gas sold in the domestic market is assumed.

Producers of petroleum products, chemical products, minerals, and metals set the prices in the domestic markets according to the Lerner pricing rule where the prices ($PD_c$) are set above the average variable costs ($PX_a$) by the mark-ups ($MKd_c$) (equation 6.2.67). The mark-ups depend on the "perceived" elasticities of demand ($DELdom_c$) and the number of firms ($N_a$) (equation 6.2.68). From equation (6.2.68) we can see that higher (lower) elasticities of demand as well as a larger (smaller) number of firms result in a decline (increase) in mark-ups. Following Francois (1998), a Cournot-Nash equilibrium in domestic markets is assumed, which implies that the parameter of conjectural variation ($\Omega$) equals unity. In other words, there are no interactions among firms.

**(6.2.67)** $$PD_c = \frac{PX_a}{(1 - MKd_c)} \qquad \forall c \in \text{icdom}_c$$

**(6.2.68)** $$MKd_c = \frac{\Omega}{N_a * DELdom_c} \qquad \forall c \in \text{icdom}_c$$

**(6.2.69)** $$ATC_a = PX_a + N_a * \frac{\sum_f fc_{f,a} * WF_f * WFDIST_{f,a} * (1 + TF_{f,a})}{QX_a}$$

where

$fc_{f,a}$ is a fixed factor per unit of output;
$WF_f$ is factor prices;
$WFDIST_{f,a}$ is sectoral-specific factor prices;
$TF_{f,a}$ is taxes on factor use; and,
$icdom_c$ is a set for domestic markets operating under imperfect competition.

Equation (6.2.69) defines the average production costs ($ATC_a$), which is the sum over average variable costs ($PX_a$) and average fixed costs (the second term in the equation). The existence of fixed costs implies internal economies of scale. Therefore, the average production costs ($ATC_a$) would equal the average variable costs ($PX_a$). In addition, the average production costs ($ATC_a$) equal the prices of domestically produced commodities ($PXC_c$).

Elasticities of demand for chemical products, petroleum products, minerals, and metals are derived from Armington CES functions, which describe substitution between imported and domestically produced commodities. This specification of elasticities of demand is a “standard” approach used in CGE models analysing imperfect competition (e.g. Francois, 1998). The elasticities of demand ($DELdom_c$) depend on the elasticities of substitution between imported and domestically produced commodities ($\sigma_c$) and the value shares of domestically produced commodities ($SHarm_c$), as given in equations (6.2.70) and (6.2.71), respectively. The elasticities of substitution are exogenous, yet the elasticities of demand change according to the value shares. Derivation of the elasticities of demand is introduced in Appendix C.

**(6.2.70)** $$DELdom_c = \sigma_c - SHarm_c * (\sigma_c - 1) \qquad \forall c \in \text{icdom}_c$$

**(6.2.71)** $$SHarm_c = \frac{QD_c * PD_c}{QQ_c * PQS_c} \qquad \forall c \in \text{icdom}_c$$

Equation (6.2.72) represents economics profits ($EP_c$), which equals the total sales revenues (the term in brackets on the RHS[34]) minus the total production costs (last term on the RHS). With internal economies of scale, the total factor income ($YF_f$) consists of income from primary factors (the first term on the RHS) and the income from the fixed factor (the second term on the RHS), as given in equation (6.2.73).

**(6.2.72)** $$EP_c = (QD_c * PD_c + QE_c * PE_c) - QXC_c * PXC_c$$

**(6.2.73)** $$YF_f = \sum_a FD_{f,a} * WF_f * WFDIST_{f,a} + \sum_{a\$irts(a)} N_a * fc_{f,a} * WF_f * WFDIST_{f,a}$$

**(6.2.74)** $$YFDISP_f = YF_f * (1 - deprec_f) * (1 - TYF_f)$$

**(6.2.75)** $$YH_h = \sum_f (hvash_{h,f} * YFDISP_f) + hepsh_h * \sum_c EP_c$$

where $hvash_{h,f}$ is a share of income from factor f to household h

Equation (6.2.74) determines the net factor income ($YFDISP_f$), after fiscal depreciation of capital ($deprec_f$) and taxation of factor income ($TYF_f$). Finally, the total household income ($YH_f$) consists of the net factor income and economic profits, as shown in equation (6.2.75). Since there is a single representative household recorded in the database, the share of economic profit among households ($hepsh_h$) equals unity.

### 6.2.2.6 Cournot Oligopoly in the Export Gas Market

The natural gas market is assumed to exercise some market power in the export market. Both the export and domestic supply of natural gas are treated as perfect substitutes. This is because it is expected that exported and domestically produced gas has the same quality and that the unified pipeline network would allow for a flexible supply so that domestic producers of gas can switch between domestic and export markets. Due to administrative price regulation, an average cost pricing in the domestic gas market is assumed (equation 6.2.76). The export price of natural gas (*PE*) is set above the average variable cost (*PX*) by a mark-up (*MKe*) (equation 6.2.77). The mark-up (*MKe*) on the gas export depends on the number of firms (*N*) and the perceived elasticity of demand for natural gas (*DELexp*) in the export market (equation 6.2.78). A Cournot oligopoly in the export gas market with the conjectural variation ($\Omega$) equalling unity is assumed.

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[34] RHS states for right hand site.

**(6.2.76)** $PD_c = ATC_a$ $\forall c \in \text{icexp}_c$

**(6.2.77)** $$PE_c = \frac{PX_a}{(1 - MKe_c)} \qquad \forall c \in \text{icexp}_c$$

**(6.2.78)** $$MKe_c = \frac{\Omega}{N_a * DEL\exp_c} \qquad \forall c \in \text{icexp}_c$$

where $\text{icexp}_c$ is a set of commodities which face a downward sloping demand curve in the export market.

The elasticity of demand for natural gas in the export market (*DELexp*) depends on the elasticity of substitution ($\sigma_{exp}$) between the import of natural gas from Russia (*QE*) and the import of natural gas from the rest of the world (*QER*), weighted by the value share of Russian gas in the global total imports of natural gas (*SHexp*), as given in equation (6.2.79). Equation (6.2.80) defines the value share of natural gas from Russia in the global total gas imports, where *PWE* is the price of natural gas imported from Russia, *PET* is the composite world's price of natural gas, and *QET* is the global import of natural gas.

**(6.2.79)** $DEL\exp_c = \sigma_{\exp_c} - SH\exp_c * (\sigma_{\exp_c} - 1)$ $\forall c \in \text{icexp}_c$

**(6.2.80)** $$SH\exp_c = \frac{PWE_c * QE_c}{PET_c * QET_c} \qquad \forall c \in \text{icexp}_c$$

Since Russia is assumed to be a large economy regarding the natural gas market, a world import demand function for the natural gas market is incorporated. The global demand of natural gas (*QET*) is defined as a CES function over the import of natural gas from Russia (*QE*) and the import of natural gas from the ROW (*QER*) (equation 6.2.81). Equation (6.2.82) gives the corresponding demand functions for *QE*, and equation (6.2.83) determines demand for natural gas from the ROW (*QER*). In addition, *QET* and *PET* are fixed since a single country model is used. Economic profit for natural gas is defined by equation (6.2.72).

**(6.2.81)**

$$QET_c = atw_c * \left(deltw_c * QE_c^{-rhow_c} + (1 - deltw_c) * QER_c^{-rhow_c}\right)^{-\frac{1}{rhow_c)}} \qquad \forall c \in \text{icexp}_c$$

**(6.2.82)** $$QE_c = QER_c * \left(\frac{PER_c}{PWE_c} * \frac{deltw_c}{(1 - deltw_c)}\right)^{\frac{1}{(1+rhow_c)}} \qquad \forall c \in \text{icexp}_c$$

**(6.2.83)** $$QER_c * PET_c = QE_c * PWE_c + QER_c * PER_c \qquad \forall c \in \text{icexp}_c$$

#### 6.2.2.7 Calibration of Imperfect Competition

In this analysis a Cournot oligopoly with homogenous products and increasing returns to scale (IRTS) due to fixed costs is considered. Zero profit is assumed so that changes in the number of firms ensure equilibrium. Under the zero profit condition, mark-ups are related to the cost disadvantage ratio (CDR) which indicates unexploited economies of scale. A CDR measures the ratio between the average fixed cost and the average total cost (Francoise, 1998; Harrison et al., 1994).

There are different approaches for calibration of imperfect competition. For instance, using the mark-up and the number of firms, elasticities of substitution between imported and domestically produced commodities can be calibrated. Elasticities of substitution and the number of firms can be also used to calibrate the mark-up. Alternatively, the number of firms can be calibrated using elasticities of substitution and the mark-up. Therefore, two parameters could be ether estimated or assumed, where the third parameter should be calibrated (Bchir et al., 2002). Following Devarajan and Rodrik (1991), the number of firms is calibrated using the Armington elasticities from the GTAP database (Table 6.4) and by assuming a mark-up.

To our knowledge, there are no estimations on CDR as well as market power for Russia industries. Mark-ups can differ by sector and by region. Nguyen and Wigle (1992) use a mark-up of 10.5%, whereas Devarajan and Rodrik (1991) assume a mark-p of 25% for all resource-based industries which are assumed to be imperfectly competitive. According to the empirical estimation carried out by Martins et al. (1996), mark-ups for 14 OECD countries over 1970-1992 vary between zero and 30%, depending on countries and industries. Due to lack of empirical estimation for Russia, the middle value, 15%, is taken and a sensitivity analysis with respect to different mark-ups is applied in Section 7.5.4. Table 6.13 shows the calibrated perceived elasticities of demand.

**Table 6.13: Calibration of the Number of Firms and Elasticities of Demand**

| Parameters | Chemical products | Minerals | Metals | Petroleum products | Natural gas |
|---|---|---|---|---|---|
| Mark-up (MK), assumed | 15% | 15% | 15% | 15% | 15% |
| Armington elasticities ($\sigma_c$) | 1.65 | 0.45 | 1.78 | 1.05 | 3.00 |
| Perceived elasticities of demand ($PEL_c$), calibrated | -1.29 | -0.90 | -1.10 | -1.00 | -2.60 |
| Number of firms ($N_a$), calibrated | 5.14 | 7.32 | 6.01 | 6.66 | 2.56 |

Source: Own compilation.

The share of natural gas imports from Russia is 20% of the global import of natural gas (British Petroleum, 2010). The numbers of firms are calibrated to match a mark-up of 15%. Table 6.13 shows the calibrated number of firms, which should be considered as a Cournot equivalent number of firms (Devarajan and Rodrik, 1991).

### 6.2.2.8 Calibration of the Price and Quantity System under a Cournot Oligopoly

In the presence of a Cournot oligopoly, total production costs consist of fixed and variable costs. To incorporate imperfect competition with economies of scale, the calibration of the price system in the standard model is slightly modified so that fixed costs ($SAM_{FCval,a}$ and $SAM_{FCtax,a}$) are excluded from total production costs ($SAM_{total,a}$) by calibration of the activity prices (equation 6.2.84).

**(6.2.84)** $$PX0_a = \frac{(SAM_{total,a} - SAM_{FCval,a} - SAM_{FCtax,a})}{QX0_a}$$

### 6.2.2.9 Incorporation of Emissions Equation Block

Based on the GLOBE_EN model developed by Mcdonald and Thierfelder (2008), emission equations are incorporated into the model. Below the equations are listed, which are added to the standard version of the STAGE model. For example, equation (6.2.85) defines $CO_2$ emissions that results from the use of energy inputs by sectors ($CO2EMISS_{c,a}$), which equals sectoral demand for energy inputs ($QINTD_{c,a}$) multiplied by the coefficients of $CO_2$ emissions per unit ($co2co_{c,a}$). Equation (6.2.86) defines carbon dioxide emissions that results from the use of energy commodities by the household ($CO2EMISS_{c,h}$), which equals final demand for energy commodities ($QCD_{c,h}$) multiplied by the coefficients of $CO_2$ emissions per unit ($co2co_{c,h}$). The total carbon dioxide emission ($CO2EMISSTOT$) is a sum over emissions arising from industries and the representative household (equation 6.2.87).

### Carbon Dioxide Emission by Industries and Households

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**(6.2.85)** $$CO2EMISS_{c,a} = QINTD_{c,a} * co2co_{c,a} \qquad \forall c \in \mathrm{ceg}_c$$

**(6.2.86)** $$CO2EMISS_{c,h} = QCD_{c,h} * co2co_{c,h} \qquad \forall c \in \mathrm{ceg}_c$$

**(6.2.87)** $$CO2EMISSTOT = \sum_{c,a} CO2EMISS_{c,a} + \sum_{c,h} CO2EMISS_{c,h}$$

where $ceg_c$ is a sub-set for energy commodities.

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The carbon taxes on emission from industries ($TCARB_{c,a}$) is defined in equation (6.2.88). The scaling factor on carbon taxes on industries (*TCADJ*) as well as the scaling factor on carbon taxes on the household (*TCHADJ*) and the scaling factor on carbon taxes on the household and industries (*TCTCHADJ*) are instruments for policy simulations. Initially, these scaling factors equal unity, whereas carbon taxes ($tcb_{c,a}$) equal zero. The carbon taxes on $CO_2$ emissions from the household are similarly defined (equation 6.2.89). The taxes $TCARB_{c,a}$ and $TCARBH_{c,h}$ are added to the consumer prices since the carbon taxes are specific taxes. The total revenue from carbon taxes (*CARBTAX*) is defined in equation (6.2.90), which is a sum over revenues from carbon taxes on emissions from industries and the household. In addition, revenues from carbon taxes are added to the formation of the real GDP at valued added (equation 6.2.91).

### Carbon Taxes on Sectors and Households

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**(6.2.88)** $$TCARB_{c,a} = tcb_{c,a} * TCADJ * co2co_{c,a} * TCTCHADJ \qquad \forall c \in \mathrm{ceg}_c$$

**(6.2.89)** $$TCARBH_{c,h} = tchb_{c} * TCHADJ * co2co_{c,h} * TCTCHADJ \qquad \forall c \in \mathrm{ceg}_c$$

**(6.2.90)** $$CARBTAX = \sum_{c,a} (TCARB_{c,a} * QINTD_{c,a}) + \sum_{c,h} (TCARBH_{c,h} * QCD_{c,h})$$

**(6.2.91)** $$GDPVA = \sum (WF_{f} * WFDIST_{f,a} * FD_{f,a}) + MTAX + ETAX + STAX$$
$$+ FTAX + ENERGYTAX + ITAX + CARBTAX$$

where *MTAX* is the total revenue from import tariffs;
*ETAX* is the total revenue from export taxes;
*STAX* is the total revenue from sale taxes;
*FTAX* is the total revenue from taxes on factor use, and
*ITAX* is the total expenditure on production subsidies.

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#### 6.2.2.10 Model Closures

In the model, the following closure rules are assumed:

**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.

**Investment-savings closure.** Volumes of investment and the government savings are fixed and the household savings rate is variable so that the capital accounts are cleared by changes in the household savings rate.

**Government account closure.** Government consumption is fixed so that the government account is cleared by changes in policy instruments. In this analysis, either the rate of government transfers to households or the tax rate on labour income is assumed to be variable.

**Numeraire.** The consumer price index (CPI) is set as numeraire.

**International factor mobility closure.** All factors are assumed to be internationally immobile.

**Factor market closure.** Capital is assumed to be perfectly mobile among sectors; however, immobility of natural resources is assumed. Land is used by the agricultural sector only, and hence it is a *de facto* immobile resource. Furthermore, a perfectly elastic supply of land is assumed. This is because Russia has a large potential for land resources – a lot of fertile 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, a supply function for skilled and unskilled labour is incorporated:

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

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 0.30, following Böhringer et al. (2008) [35], $TYF_f$ is the tax on factor income.

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[35] Evers et al. (2008) confirm this order of magnitude, finding that the mean labour supply elasticity for men equals 0.07, whereas that for women equals 0.43.

# 7 Results of Policy Simulations

## 7.1 Overview of Policy Simulations

In this analysis, an introduction of carbon taxes on coal, natural gas, petroleum products, crude oil, and gas manufacture used by households and industries is simulated. Electricity is not subject to carbon taxation. The magnitude of carbon taxation aims at a targeted reduction of carbon dioxide emissions by 10% through a proportional increase in tax rates on carbon dioxide emissions. Carbon taxes differ among energy commodities and these also slightly differ among sectors according to their $CO_2$ coefficients (Table 6.7). Three experiments are considered:

1) **CT_HS.** An introduction of carbon taxes compensated by an increase in lump-sum transfers to households.

2) **CT_LT under perfect competition.** An introduction of carbon taxes compensated by a reduction of tax rates on income from skilled and unskilled labour under perfect competition in output markets.

3) **CT_LT under a Cournot oligopoly.** An introduction of carbon taxes compensated by a reduction of tax rates on income from skilled and unskilled labour under a Cournot oligopoly with increasing return to scale in the markets for natural gas, petroleum products, chemical products, metals, and minerals. Moreover, the effects of carbon taxes under a Cournot oligopoly with blocked entry and exit are compared with those under a Cournot oligopoly with free entry and exit.

The experiment CT_HS is considered as a reference experiment since revenues from carbon taxes are returned to households in lump-sum form (Section 7.2). In Section 7.3, the results under a CT_HS are compared with those under a CT_LT with perfect competition so that the relevance of such a revenue recycling strategy is examined. Substituting environmental taxes for labour taxes is often considered as desirable, especially for Western economies, since it also addresses unemployment concerns (Bovenberg and van der Ploeg, 1994). Moreover, some European countries have already implemented such environmental tax reforms, where an introduction of various environmental taxes (carbon dioxide or sulphur dioxide) is compensated by reductions in personal income taxes or social security contributions (Bosquet, 2000). The motivation for such a policy would be valid for Russia, too, since the level of unemployment in Russia accounted for 7.5% of the total labour force in 2010 (FSSS, 2012a). Moreover, distortions from labour taxation may be substantial in Russia: both taxes on labour income and social security contributions accounted for 27% of total government revenues in 2010 (FSSS, 2012b). Furthermore, substituting carbon taxes for labour taxes explicitly addresses the issue of income inequality, which is of high relevance for Russia. For example, the Gini coefficient for Russia was 0.42 in 2009 (FSSS, 2011).

Alternatively, revenues from carbon taxes can be refunded through a reduction in capital taxes, trade taxes, and consumption taxes or some other taxes. Such revenue recycling schemes are not considered in this analysis since this would require substantial modifications of the model framework and database. Moreover, it raises concerns with respect to political feasibility of other possible revenue recycling strategies.

Finally, the results from a CT_LT under perfect competition are compared with those under a Cournot oligopoly in output markets so that the relevance of the market structure is investigated (Section 9.5).

The result section for each experiment is divided into four main parts:

1) **Macroeconomic and fiscal effects.** In this part, the macroeconomic effects such as net welfare effects as well as changes in factor prices, factor supply and tax revenues in response to carbon taxation are discussed.

2) **Sectoral effects.** This part is aimed at providing an overview of the sectoral effects due to carbon taxation: for example, changes in producer and consumer prices as well as changes in domestic production and consumption are discussed. Moreover, technological changes in the electricity sector are analysed.

3) **Carbon dioxide emissions.** This part gives information about the changes in $CO_2$ emissions by sectors. This part is not explicitly discussed in the experiment CT_LT under a Cournot oligopoly because the results are very similar to that under perfect competition.

4) **Carbon taxation and income equity.** In this part, the effects of carbon taxation on income distribution are analysed. By using a simple micro-accounting approach, it is shown how carbon taxes compensated by an increase in lump-sum transfers as well as a reduction in labour taxes affect the consumption expenditure as well as factor income and net income by different household groups.

Furthermore, the experiments CT_HS and CT_LT under perfect competition are accompanied by sensitivity analyses to ensure the robustness of the results and to recognize important determinants:

a) Emission reduction targets (Section 7.4.1).

b) Substitution between intermediates and the value added-energy aggregate (Section 7.4.2).

c) Substitution between labour and the capital-energy aggregate (Section 7.4.3).

d) Labour supply elasticity (Section 7.4.4).

e) Substitution between capital and energy (Section 7.4.5).

f) Capital mobility and immobility (Section 7.4.6).

g) Substitution among power generation technologies (Section 7.4.7).

For the experiment CT_LT under a Cournot oligopoly, only one sensitivity analysis is run where different values of mark-ups are analysed.

## 7.2 Substituting Carbon Taxes for Lump-Sum Transfers

### 7.2.1 Macroeconomic and Fiscal Effects

#### 7.2.1.1 Macroeconomic Effects

Table 7.1 summarizes the macroeconomic effects of the introduction of carbon taxes compensated by an increase in lump-sum transfers from the government to the representative household.

**Table 7.1: Macroeconomic Effects**

| | **Changes in million USD** | **Changes in per cent** |
|---|---|---|
| Equivalent variation | -2,176 | -0.75 |
| Exchange rate | n.a. | 0.08 |
| Real GDP at value added | -2,399 | -0.43 |
| Rate of lump-sum transfers | n.a. | 10.78 |
| **Household expenditure:** | -1,278 | -0.44 |
| Household income | -7,565 | -2.05 |
| Household savings | 224 | 0.14 |
| Lump-sum transfers | 6,511 | 8.51 |

Source: Model simulation results.

Introducing carbon taxes leads to welfare losses measured by equivalent variation (EV) of 0.75% of base household expenditure. Household expenditures – household income minus savings and plus lump-sum transfers – are reduced because of a decline in household income as well as an increase in household savings, even though lump-sum transfers from the government to the household are increased. Despite a reduction in household income, household savings are increased due to a higher household savings rate. According to the model closures, the government savings rate and investment are fixed, which implies an investment driven closure. Due to a decline in household income, the household savings rate is increased by 0.38% to match fixed investment. Alternatively, if the savings rate is fixed, investment would decrease due to decreasing household income, yet decreases in the final consumption would be less pronounced compared that those under an investment driven closure.

#### 7.2.1.2 Factor Markets

Table 7.2 shows changes in factor income as well as factor supply and factor prices.

**Table 7.2: Change in Factor Income, Factor Prices, and Factor Supply**

| | Household income (million USD) | Factor prices (per cent) | Factor supply (per cent) |
|---|---|---|---|
| Land | -28 | fixed | -0.42 |
| Unskilled labour | -1,343 | -1.11 | -0.34 |
| Skilled labour | -527 | -0.94 | -0.28 |
| Capital | -5,157 | -2.59 | fixed |
| Natural Resources | -510 | -7.41 | fixed |
| **Total** | **-7,565** | **n.a.** | **n.a.** |

Source: Model simulation results.

Household income – income from capital, labour, land, and natural resources minus taxes on factor income and a fiscal depreciation of capital – decreases by 7,565 million USD because of decreased income from all production factors. The increased energy cost negatively affects the competitiveness of the Russian economy, resulting in reductions of domestic production in the most sectors. Hence, demand for production factors decreases, resulting in lower factor supply as well as lower returns to factors. For example, a reduction in capital income results from a lower return to capital, whereas capital stock is fixed. Since capital is assumed to be international immobile, the burden of carbon taxes is partially borne by capital in terms of decreasing capital income. This indicates the so called tax-shifting effect in terms of lower capital income (de Mooij and Bovenberg, 1998). Both lower labour supply and lower wages lead to a reduction in income from unskilled and skilled labour. Decreases in production of natural gas, coal, agriculture, and minerals are associated with lower returns to natural resources. Hence, there is a reduction in income from natural recourses. This indicates a tax-shifting effect between labour and natural resources (Bento and Jacobsen, 2007; Bovenberg and van der Ploeg, 1998). Therefore, the burden of carbon taxes is borne not only by labour, yet this is also borne by capital and natural resources. Introducing carbon taxes leads to a reduction in domestic production of agricultural products so that there is a decline in demand for land. Supply of land is assumed to be perfectly elastic in Russia. Therefore, the decreased demand for land is associated with lower land supply, which results in lower income from land.

#### 7.2.1.3 Government Budget

Table 7.3 shows the changes in government revenues and expenditures from trade and domestic taxes.

**Table 7.3: Changes in Government Revenues and Expenditures from Trade and Domestic Taxes**

| | Changes in million USD | Changes in per cent |
|---|---:|---:|
| **Government revenues:** | 5,850 | n.a. |
| Export taxes | 499 | 1.95 |
| Import taxes | -56 | -0.57 |
| Carbon taxes | 7,977 | n.a. |
| Consumption taxes | -1,307 | -2.62 |
| Tax on unskilled labour income | -478 | -1.45 |
| Tax on skilled labour income | -188 | -1.22 |
| Social security contribution from unskilled labour | -46 | -1.43 |
| Social security contribution from skilled labour | -18 | -1.21 |
| Capital tax | -488 | -2.58 |
| Mineral resource extraction taxes | -43 | -1.82 |
| Land tax | -2 | -0.42 |
| **Government expenditures:** | 6,506 | n.a. |
| Lump-sum transfer | 6,511 | 8.51 |
| Production subsidies | -5 | -0.74 |

Source: Model simulation results.

According to the model closure rule, government consumption is fixed and therefore the net government income – revenues from taxes minus government subsidies and transfers – changes. Introducing carbon taxes compensated by an increase in lump-sum transfers results in decreases in revenues from almost all taxes, whereas the only total revenue from carbon taxes as well as export taxes is increased. The main consideration with respect to changes in tax revenues is that higher (lower) tax revenues reduce (increase) the cost of carbon taxation.

**Export taxes.** As shown in Table 7.4, the largest source of export tax revenues is the export tax on crude oil, which accounts for 69.6% of the total revenue from export taxes, followed by petroleum products (9.2%), metals (6.9%), and natural gas (6.1%).

**Table 7.4: Changes in Revenues from Export Taxes**

| | Baseline revenue shares (per cent) | Changes in revenues from export taxes (million USD) | Changes in export supply (per cent) |
|---|---|---|---|
| Coal | 0.1 | 2.07 | 7.52 |
| Crude oil | 69.6 | 357.62 | 1.93 |
| Natural gas | 6.1 | 335.23 | 24.54 |
| Petroleum products | 9.2 | 34.09 | 1.37 |
| Wood products | 2.1 | -70.63 | -13.27 |
| Chemical products | 2.8 | -57.56 | -8.26 |
| Mineral products | 0.2 | -1.21 | -2.90 |
| Metals | 6.9 | -112.58 | -6.43 |
| Metal products | 0.1 | -0.71 | -3.09 |
| Electronic equipment | 0.02 | -0.23 | -3.91 |
| Machinery equipment | 0.3 | -0.78 | -1.13 |
| Agricultural products | 0.01 | 0.01 | 0.44 |
| Transport equipment | 0.2 | 0.41 | 0.59 |
| Minerals | 0.6 | 3.75 | 2.19 |
| Textiles | 0.4 | -0.08 | -0.14 |
| Paper products | 1.3 | 9.67 | 2.83 |
| **Total** | **100** | **499.04** | **n.a.** |

Source: Version 7 of the GTAP database and model simulation results.

Introducing carbon taxes leads to increases in the revenues from export taxes on some energy commodities and non-energy intensive commodities. The reasons for this are both increases in export supplies and a depreciation of the currency. Domestic producers of energy commodities as well as non-energy intensive commodities become more competitive in export markets because of decreasing production costs. Carbon taxes are levied only on domestic consumption of energy. As a result, there are increases in export supply of coal, crude oil, natural gas, petroleum products, agricultural products, transport equipment, minerals and paper products, which are associated with increases in revenues from export taxes on these commodities. In particular, the increases in revenues from export taxes on crude oil and natural gas are strong pronounced due to high increases in export supply as well as high export tax rates. In contrast, domestic producers of energy intensive sectors become less competitive in export markets because of increased production costs. Therefore, there are decreases in export supply of energy intensive commodities, such as wood products, chemical products, mineral products, metals, and metal products, which are associated with lower revenues from export taxes. Overall, the total revenue from export taxes increases by 499 million USD, since the increases in revenues from export taxes on energy commodities as well as non-energy intensive commodities overweigh the decreases in revenues from export taxes on energy intensive commodities. The increased total revenue from export taxes, to certain extent, reduces the cost of carbon taxation since these accumulate higher lump-sum transfers to households.

**Import tariffs.** As shown in Table 7.5, the largest source of import tariff revenues is the import tariff on machinery equipment, which account for 18.0% of the total revenue from import tariffs, followed by food products (16.2%), transport equipment (15.4%), and textile products (14.9%).

**Table 7.5: Changes in Revenues from Import Tariffs**

| | Baseline revenue shares (per cent) | Changes in revenues from import tariffs (million USD) | Changes in import demand (per cent) |
|---|---:|---:|---:|
| Coal | 0.01 | -0.19 | -22.73 |
| Crude oil | 0.00003 | -0.0002 | -5.23 |
| Natural gas | 0.00001 | -0.0002 | -25.04 |
| Petroleum products | 0.04 | -0.15 | -4.28 |
| Electricity | 0.1 | 0.39 | 3.50 |
| Wood products | 3.4 | 7.23 | 2.12 |
| Chemical products | 12.5 | -1.26 | -0.18 |
| Mineral products | 2.5 | 0.68 | 0.20 |
| Metals | 2.0 | 0.57 | 0.22 |
| Metal products | 3.5 | -1.87 | -0.63 |
| Electronics equipment | 5.6 | -0.17 | -0.11 |
| Machinery equipment | 18.0 | -8.51 | -0.56 |
| Agricultural products | 3.2 | -3.45 | -1.18 |
| Food products | 16.2 | -17.37 | -1.18 |
| Transport equipment | 15.4 | -12.08 | -0.89 |
| Minerals | 0.2 | -0.65 | -4.32 |
| Textiles | 14.9 | -14.47 | -1.08 |
| Paper products | 2.6 | -4.27 | -1.80 |
| **Total** | **100** | **-55.59** | **n.a.** |

Source: Version 7 of the GTAP database and model simulation results.

Introducing carbon taxes leads to increases in the revenues from import tariffs on electricity, wood products, mineral products, and metals, because of increases in import demand for energy intensive commodities as well as a depreciation of the currency. Most domestically produced energy intensive commodities become less competitive in domestic markets so that domestic consumers increase their demand for relative less expensive imports. In contrast, revenues from import tariffs on energy commodities as well as non-energy intensive commodities, such as agriculture, food products, and textiles, decrease because of lower household income as well as a lower import demand via a substitution effect in favour of domestically produced commodities. Overall, the total revenue from import tariffs is reduced by 55.6 million USD since the decreases in revenues from import tariffs on energy and non-energy intensive commodities are more pronounced compared to the increases in revenues from import tariffs on some energy intensive commodities.

**Carbon taxes and lump-sum transfers.** Lump-sum transfers paid by the government to households are increased by 6,511 million USD because of an increase in the revenue from carbon taxes (7,977 million USD). According to the policy simulation, the revenue from carbon taxes is not directly returned to households, yet the rate of lump-sum transfers clears the government account in response to changes in all taxes. Therefore, due to various macroeconomics effects, the revenue from carbon taxes differs from the increase in lump-sum transfers.

**Consumption taxes.** The revenue from consumption taxes decreases by 1,307 million USD. Consumption taxes include value added taxes and excise taxes, which both are a significant part of the Russian government budget. The reduction in the revenue from consumption taxes results from decreases in total domestic consumption of all commodities (see Section 7.2.2.2).

**Factor taxes.** As mentioned, introducing carbon taxes leads to decreases in the returns to capital, natural resources, land and labour. Moreover, supply of unskilled and skilled labour as well as land is reduced because of lower factor demand. As a result, there are decreases in the revenues from taxes on labour income, social security contributions, the tax on capital income as well as taxes on natural resources and land (Table 7.3).

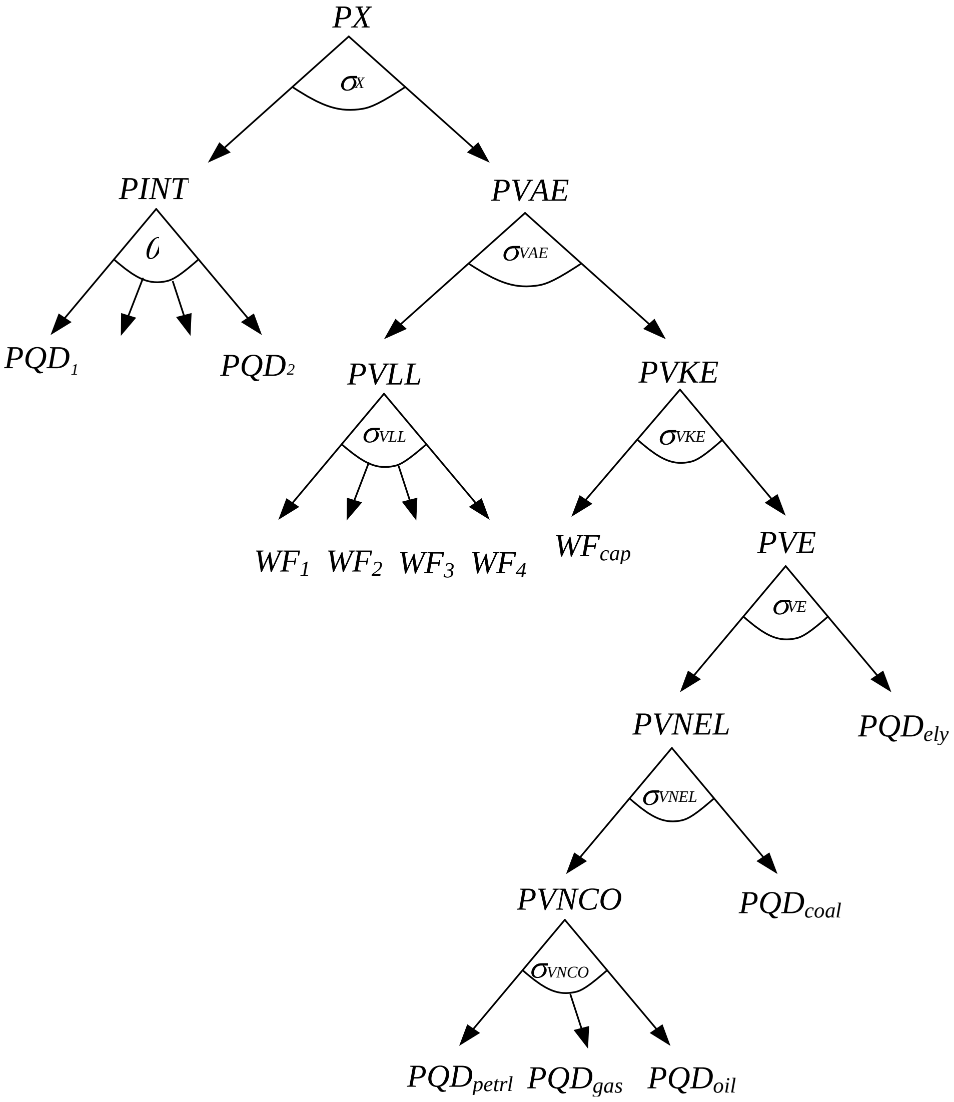
**Production subsidies.** The agricultural sector receives a production subsidy only. Decreasing domestic demand for agricultural products leads to a reduction in the total production of agricultural products by 0.33%. As a result, government expenditures on production subsidies decrease by 5.0 million USD.

## 7.2.2 Sectoral Effects

### 7.2.2.1 Producer and Consumer Prices

Figure 7.1 illustrates the price system in the modified version of the STAGE model.

**Figure 7.1: Price System for Non-Energy Producing Sectors**



Source: Own compilation based on McDonald (2009).

Table 7.6 reveals the changes in production costs resulting from the introduction of carbon taxes compensated by an increase in lump-sum transfers. Changes in energy costs are indicated by the activity prices of energy aggregates (PVE). For example, introducing carbon taxes leads to increases in PVE of almost all sectors, whereas PVE of the petroleum product sector decreases because of a lower producer price of crude oil (Column 6 of Table 7.6). The carbon tax is not levied on usage of crude oil by the petroleum product sector. Capital and the energy aggregate build a capital-energy aggregate, whose average cost is indicated by an activity price of capital-energy aggregate (PVKE). Due to lower capital costs, PVKE of some capital intensive sectors are reduced since the reductions in capital costs overweigh the increases in energy costs (Column 5 of Table 7.6). For example, there are decreases in PVKE of crude oil, food products, construction, trade products, transport equipment, private and public services, minerals, and paper products. On the next level of the production nest, the aggregate of capital-energy is nested with an aggregate of primary factors to form an aggregate of value added-energy, whose average cost is defined by an activity price of value added-energy aggregate (PVAE). The decreases in wages for unskilled and skilled labour lead to lower labour costs for industries. As a result, the activity prices of primary factor aggregate (PVLL) are reduced in almost all sectors with the decreases in PVLL of the coal, natural gas, and mineral sectors being more pronounced compared to those in other sectors (Column 4 of Table 7.6). This is because the primary factor aggregate of these sectors includes natural resources, whose prices decrease as well. PVLL for the crude oil sector increases because the return to natural resources used by the oil sector becomes higher. Furthermore, decreasing PVLL leads to reductions in PVAE of agricultural products and textiles as well as other labour intensive sectors (Column 3 of Table 7.6). Finally, an aggregate of intermediates and an aggregate of value added-energy are nested to form output. The average production cost is a weighted average cost of intermediates and value added-energy aggregates. Activity prices of intermediate aggregate (PINT) increase in energy intensive sectors: chemical products, metals, metal products, electronic equipment, machinery equipment, and transport equipment because of higher consumer prices of some intermediates (Column 2 of Table 7.6). Overall, introducing carbon taxes compensated by higher lump-sum transfers leads to increases in average production costs (PX) in energy intensive sectors, such as electricity, wood products, chemical products, and minerals mainly because of increased energy costs (Column 1 of Table 7.6). In contrast, average production costs of labour- and some capital intensive commodities, such as agriculture, food products, and trade products, are reduced since the decreases in factor costs overweigh the increases in energy costs.

**Table 7.6 Changes in Activity Prices (per cent)**

|  | (1)<br>PX | (2)<br>PINT | (3)<br>PVAE | (4)<br>PVLL | (5)<br>PVKE | (6)<br>PVE |
|---|---|---|---|---|---|---|
| Coal | -4.14 | -0.03 | -7.76 | -12.29 | 4.99 | 7.83 |
| Crude oil | -0.48 | -0.34 | -0.55 | 0.76 | -1.79 | 8.07 |
| Natural gas | -2.45 | -1.37 | -3.73 | -7.95 | 1.47 | 10.12 |
| Petroleum products | -1.06 | -0.69 | -1.07 | -1.08 | -1.07 | -0.77 |
| Gas manufacturing | -0.36 | -0.43 | -0.31 | -1.06 | 0.82 | 6.47 |
| Electricity* | 6.85 | -0.88 | n.a. | n.a. | n.a. | n.a. |
| Wood products | 2.81 | -0.15 | 4.67 | -1.09 | 6.04 | 6.58 |
| Chemical products | 1.38 | 0.33 | 2.20 | -1.08 | 2.96 | 4.20 |
| Mineral products | 0.94 | -0.10 | 1.94 | -1.09 | 4.03 | 7.25 |
| Metals | 0.98 | 0.24 | 1.79 | -1.09 | 2.53 | 6.79 |
| Metal products | 0.61 | 0.61 | 0.61 | -1.09 | 2.86 | 6.52 |
| Electronic equipment | 0.77 | 0.34 | 1.56 | -1.08 | 2.99 | 6.41 |
| Transports | 0.40 | -0.52 | 0.88 | -1.08 | 1.70 | 5.44 |
| Machinery equipment | 0.20 | 0.32 | 0.06 | -1.08 | 2.16 | 7.01 |
| Water | 0.09 | -0.48 | 0.36 | -1.06 | 2.37 | 6.60 |
| Agricultural products | -0.43 | -0.43 | -0.44 | -0.82 | 0.78 | 5.18 |
| Food products | -0.50 | -0.48 | -0.55 | -1.09 | -0.30 | 6.73 |
| Construction | -0.75 | 0.28 | -1.71 | -1.09 | -2.16 | 6.00 |
| Trade products | -1.66 | -0.15 | -2.29 | -1.09 | -2.44 | 5.61 |
| Transport equipment | -0.22 | 0.04 | -1.50 | -1.08 | -2.48 | 8.79 |
| Private services | -1.16 | -0.57 | -1.46 | -1.03 | -1.71 | 4.97 |
| Public services | -0.70 | -0.35 | -0.87 | -1.01 | -0.31 | 6.90 |
| Minerals | -1.73 | -0.55 | -2.66 | -2.80 | -2.55 | 6.41 |
| Textiles | -0.15 | -0.18 | -0.10 | -1.09 | 1.28 | 6.97 |
| Paper products | -0.87 | -0.42 | -1.83 | -1.08 | -2.17 | 11.24 |

Source: Model simulation results.

Changes in production costs determine changes in producer prices. Table 7.7 shows the changes in producer and consumer prices. Three commodity (sector) groups are distinguished: (1) energy commodities, (2) energy intensive commodities, and (3) non-energy intensive commodities. The first group, *energy commodities*, includes coal, crude oil, natural gas, gas manufacture, and petroleum products. The second group, *energy intensive commodities*, includes electricity, wood products, chemical products, mineral products, metals, metal products, electronic equipment, transports, machinery equipment, and water. These commodities are the most energy intensive compared to other commodities so that introducing carbon taxes leads to increases in producer prices because of increased energy costs (Column 2 of Table 7.7). The third group, *non-energy intensive commodities*, includes agricultural products, food products, construction, trade products, transport equipment, private services, public services, minerals, textiles, and paper products. In comparison to energy intensive commodities, producer prices of non-energy intensive commodities decrease because of decreased labour and capital costs.

**Table 7.7: Changes in Producer and Consumer Prices (per cent)**

| | (1) Consumer prices | (2) Producer prices | (3) Import and export prices | (4) Competitive-ness indicator |
|---|---|---|---|---|
| Coal | 22.38 | -7.12 | 0.08 | 7.75 |
| Crude oil | 5.92 | -1.24 | 0.08 | 1.33 |
| Natural gas | 13.16 | -2.45 | (-2.45) 0.08 | 2.59 |
| Petroleum products | 2.55 | -1.37 | 0.08 | 1.46 |
| Gas manufacturing | 19.44 | -0.47 | 0.08 | 0.55 |
| Electricity | 6.84 | 6.91 | 0.08 | -6.39 |
| Wood products | 2.59 | 4.59 | 0.08 | -4.32 |
| Chemical products | 1.34 | 2.42 | 0.08 | -2.28 |
| Mineral products | 0.82 | 0.99 | 0.08 | -0.91 |
| Metals | 1.65 | 1.91 | 0.08 | -1.80 |
| Metal products | 0.49 | 0.73 | 0.08 | -0.65 |
| Electronic equipment | 0.24 | 0.92 | 0.08 | -0.83 |
| Transports | 0.42 | 0.46 | 0.08 | -0.39 |
| Machinery equipment | 0.16 | 0.22 | 0.08 | -0.14 |
| Water | 0.09 | 0.09 | 0.08 | -0.01 |
| Agricultural products | -0.42 | -0.47 | 0.08 | 0.55 |
| Food products | -0.41 | -0.55 | 0.08 | 0.63 |
| Construction | -0.73 | -0.76 | 0.08 | 0.84 |
| Trade products | -1.65 | -1.68 | 0.08 | 1.78 |
| Transport equipment | -0.13 | -0.32 | 0.08 | 0.39 |
| Private services | -1.07 | -1.25 | 0.08 | 1.34 |
| Public services | -0.68 | -0.70 | 0.08 | 0.78 |
| Minerals | -2.14 | -2.58 | 0.08 | 2.72 |
| Textiles | -0.03 | -0.20 | 0.08 | 0.28 |
| Paper products | -0.76 | -1.24 | 0.08 | 1.33 |

Source: Model simulation results.

Due to a depreciation of the currency, import prices (PM) as well as export prices (PE) are increased (Column 3 of Table 7.7). In contrast, the export price of natural gas is reduced by 2.45% because of an increase in the export supply of natural gas – Russia is modelled as a large economy with respect to the natural gas market. Consumer prices (PQD) are defined as the weighted averages of the prices of domestically produced commodities (PD) and the prices of imported commodities (PM) plus sales taxes and carbon taxes. Introducing carbon taxes results in higher consumer prices of energy commodities (Column 1 of Table 7.7). Moreover, the consumer prices of energy intensive commodities, such as electricity, wood products, and chemical products, increase because of both higher producer prices and a depreciation of the currency. Despite the increases in import prices, consumer prices of non -

energy intensive commodities, such as food products, textiles, and trade products, are reduced because of lower domestic producer prices.

Following Rivers (2010) and Bruvoll and Faehn (2006), competitiveness of domestic producers is defined as a relative change in the ratio of import prices to domestic producer prices. Column 4 of Table 7.7 shows the percentage changes in the ratio between import and domestic prices. Positive (negative) values indicate increases (decreases) in competitiveness. Decreases in production costs as well as a depreciation of the currency makes domestic producers of energy commodities as well as non-energy intensive commodities more competitive in domestic and export markets compared to foreign firms. In contrast, domestically produced energy intensive commodities lose their market shares in domestic and export markets.

#### 7.2.2.2 Production and Consumption

Table 7.8 shows the sectoral effects of the introduction of carbon taxes.

**Energy commodities.** Carbon taxes are imposed on the composite of imported and domestically produced coal, crude oil, petroleum products, natural gas, and gas manufacture so that higher consumer prices lead to decreases in the demand for imported as well as domestically produced energy (Column 5 and 4 of Table 7.8). Because of both a depreciation of the currency and lower production costs, domestic producers of energy commodities become more competitive in domestic and export markets compared to foreign firms (Column 4 of Table 7.7).

**Table 7.8: Sectoral Effects of Carbon Taxation (percentage changes)**

| | (1) Production costs | (2) Domestic production | (3) Export supply | (4) Domestic demand | (5) Import demand | (6) Domestic consumption |
|---|---|---|---|---|---|---|
| **Energy sectors:** | | | | | | |
| Coal | -4.14 | -5.11 | 7.52 | -13.41 | -22.73 | -14.98 |
| Crude oil | -0.48 | 0.30 | 1.93 | -1.91 | -5.23 | -1.95 |
| Natural gas | -2.45 | -1.94 | 24.54 | -6.64 | -25.04 | -7.14 |
| Petroleum products | -1.06 | -1.93 | 1.37 | -2.81 | -4.28 | -2.81 |
| Gas manufacture | -0.36 | -13.28 | -12.18 | -13.55 | -14.21 | -13.55 |
| **Energy intensive sectors:** | | | | | | |
| Electricity | 6.85 | -5.75 | -17.32 | -5.64 | 3.50 | -5.55 |
| Wood products | 2.81 | -8.46 | -13.27 | -5.26 | 2.12 | -2.10 |
| Chemical products | 1.38 | -5.85 | -8.26 | -3.92 | -0.18 | -2.23 |
| Mineral products | 0.94 | -1.22 | -2.90 | -1.11 | 0.20 | -0.87 |
| Metals | 0.98 | -4.74 | -6.43 | -2.97 | 0.22 | -2.54 |
| Metal products | 0.61 | -2.06 | -3.09 | -1.83 | -0.63 | -1.40 |
| Electronic equipment | 0.77 | -2.58 | -3.91 | -2.29 | -0.11 | -0.54 |
| Transports | 0.40 | -1.38 | -2.03 | -1.26 | -0.90 | -1.22 |
| Machinery equipment | 0.20 | -0.88 | -1.13 | -0.84 | -0.56 | -0.73 |
| Water | 0.09 | -0.73 | -0.75 | -0.73 | -0.71 | -0.73 |
| **Non-energy intensive sectors:** | | | | | | |
| Agriculture | -0.43 | -0.33 | 0.44 | -0.39 | -1.18 | -0.47 |
| Food products | -0.50 | -0.18 | 0.68 | -0.26 | -1.18 | -0.46 |
| Construction | -0.75 | -0.13 | 1.53 | -0.17 | -2.27 | -0.26 |
| Trade products | -1.66 | -0.30 | 3.26 | -0.33 | -1.99 | -0.36 |
| Transport equipment | -0.22 | 0.004 | 0.59 | -0.19 | -0.89 | -0.53 |
| Private services | -1.16 | -0.24 | 2.27 | -0.42 | -1.20 | -0.53 |
| Public services | -0.70 | -0.01 | 1.55 | -0.01 | -0.75 | -0.03 |
| Minerals | -1.73 | -1.47 | 2.19 | -3.15 | -4.32 | -3.35 |
| Textiles | -0.15 | -0.60 | -0.14 | -0.70 | -1.08 | -0.94 |
| Paper products | -0.87 | 0.90 | 2.83 | 0.14 | -1.80 | -0.57 |

As a result, relative decreases in the consumption of imported energy commodities are more pronounced than those of domestically produced commodities. As shown in Table 7.9, in absolute terms, reductions in demand for domestically produced energy inputs, however, are much higher than imported commodities since the shares of imported energy in domestic markets are relatively small (Table 6.1).

**Table 7.9: Changes in Domestic Production, Export Supply, Domestic and Import Demand and Domestic Consumption (million tons of oil equivalent)**

| | Domestic production | Domestic demand | Export supply | Import demand | Domestic consumption |
|---|---|---|---|---|---|
| Coal | -7.65 | -11.86 | 4.21 | -3.91 | -15.77 |
| Crude oil | 1.27 | -3.51 | 4.78 | -0.12 | -3.63 |
| Natural gas | -5.31 | -15.47 | 10.16 | -1.61 | -17.08 |
| Petroleum products | -3.50 | -4.02 | 0.51 | -0.02 | -4.04 |
| Gas manufacture | -19.55 | -15.95 | -3.60 | -0.02 | -15.97 |
| Electricity | -13.11 | -12.76 | -0.36 | 0.08 | -12.67 |

Source: Model simulation results.

Overall, introducing carbon taxes leads to a reduction in total domestic consumption of all energy commodities with the relative reduction in demand for coal and gas manufacture being more pronounced compared to those of petroleum products, crude oil and natural gas (Column 6 of Table 7.8). The reason for this is that coal is the most carbon-intensive energy input. Furthermore, due to declining production costs, introducing carbon taxes leads to increases in the export supply of natural gas by 24.5%, coal (7.5%), crude oil (1.9%), petroleum products (1.4%), whereas the export supply of gas manufacture is reduced by 12.2% because of a strong negative output effect. A strong reduction in the domestic demand for gas manufacture results in lower profitability of this sector so that production factors leave out the gas manufacture sector in favour of other sectors. Moreover, the substitution effect between export and domestic supply in the gas manufacture sector is less pronounced compared to that in other energy sectors because of a smaller reduction in production costs of gas manufacture. Despite the increases in export supplies of energy, there are decreases in total domestic production of energy inputs, whereas production of crude oil is slightly increased by 0.3% due to higher export supply (Column 2 of Table 7.8).

**Energy intensive commodities.** Increases in energy costs lead to higher producer prices of energy intensive commodities such as electricity[36], wood products, chemical products, and

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[36] Electricity is an energy input as well as energy intensive good. In this article, electricity is classified as an energy intensive good.

metals. Consumption of electricity is not subject to carbon taxation, yet the electricity sector is greatly impacted from increased energy costs. The electricity sector is the largest domestic consumer of coal and gas as well as one of the largest consumers of petroleum products (Table 6.3). As a result, electricity-intensive sectors are adversely affected by a high electricity price. Hence, there are decreases in domestic demand for all domestically produced energy intensive commodities (Column 4 of Table 7.8). In addition, reductions in demand for energy intensive commodities are also exacerbated by decreased household income. Since domestic producers of energy intensive commodities become less competitive compared to foreign firms (Column 4 of Table 7.7), there are increases in import demand for electricity, wood products, mineral products and metals (Column 5 of Table 7.8). In contrast, import demand for other energy intensive commodities, such as chemical products, metal products, electronic equipment, transports, machinery equipment, and water is reduced because of lower household income. Furthermore, export supply of all energy intensive commodities is decreased due to increased production costs (Column 3 of Table 7.8). Overall, total domestic consumption as well as domestic production of all energy intensive commodities is reduced (Column 6 and 2 of Table 7.8).

**Non-energy intensive commodities.** Introducing carbon taxes compensated by an increase in lump-sum transfers leads to reductions in consumption of almost all domestically produced non-energy intensive commodities, such as food products, trade products, and textiles (Column 4 of Table 7.8). The reason for this is lower household income. Furthermore, there are reductions in consumption of imported non-energy intensive commodities, which are more pronounced than those of domestically produced commodities. Compared to energy intensive commodities, production costs in labour and capital intensive sectors are reduced since the reduction in costs for primary factors more than compensates increases in energy costs (Column 1 of Table 7.8). Both lower consumer prices and a depreciation of the currency make domestically produced non-energy intensive commodities less expensive compared to imports, thereby increasing competitiveness of the former. Moreover, domestically produced non-energy intensive commodities become more competitive in export markets. Hence, there are increases in export supply of almost all non-energy intensive commodities, such as food products, trade products, and minerals (Column 3 of Table 7.8). Export supply of textiles, however, is reduced because of a strong output effect so that production factors leave out this sector. Overall, domestic consumption and production of almost all non-energy intensive commodities is reduced, whereas there is an increase in domestic production of paper products and transport equipment due to both higher export and domestic demand (Column 2 and 6 of Table 7.8).

### 7.2.2.3 Final Consumption

Total domestic demand consists of four demand categories: household demand, intermediate demand, government demand, and investment demand. According to the model closure, investment and government consumption is fixed so that changes in household consumption are considered only. Government consumption consists mainly of consumption of public services, whose share accounts for approximately 92% of the total government consumption expenditure. Moreover, the government is the largest domestic consumer of public services, whose consumption share amounts to 86% of total domestic consumption of public services. Furthermore, changes in $CO_2$ emissions by industries are discussed below.

As shown in Table 7.10, households spend about 23.7% of total income on the consumption of trade commodities, followed by food products (18.0%), transports (8.3%), and private services (8.2%). Introducing carbon taxes leads to decreases in the household consumption of coal, natural gas, gas manufacture, and electricity with the relative reduction in demand for coal being more pronounced compared to those of other energy commodities because of high carbon intensity of coal. Despite the carbon taxation, the final consumption of petroleum products is increased slightly by 0.3% via a substitution effect between energy commodities. Since the increase in consumer price of petroleum products is less pronounced compared to those of other energy commodities (Table 7.10).

**Table 7.10: Changes in Final Consumption (per cent)**

| | Baseline expenditure shares | Changes in consumption |
|---|---|---|
| Coal | 0.1 | -15.99 |
| Natural gas | 0.1 | -9.14 |
| Petroleum products | 3.4 | 0.26 |
| Gas manufacture | 1.2 | -13.92 |
| Electricity | 7.5 | -3.76 |
| Wood products | 1.1 | -3.41 |
| Chemical products | 2.9 | -2.21 |
| Mineral products | 0.4 | -1.71 |
| Metals | 0.01 | -2.51 |
| Meta products | 0.6 | -1.39 |
| Electronic equipment | 0.2 | -1.14 |
| Transports | 8.3 | -1.32 |
| Machinery equipment | 3.2 | -1.06 |
| Water | 0.8 | -0.99 |
| Agriculture | 7.7 | -0.49 |
| Food products | 18.0 | -0.49 |
| Construction | 0.5 | -0.18 |
| Trade products | 23.7 | 0.76 |
| Transport equipment | 3.3 | -0.78 |
| Private services | 8.2 | 0.17 |
| Public services | 4.0 | -0.23 |
| Minerals | 0.002 | 1.27 |
| Textiles | 4.1 | -0.87 |
| Paper products | 0.5 | -0.14 |
| **Total** | **100** | **n.a.** |

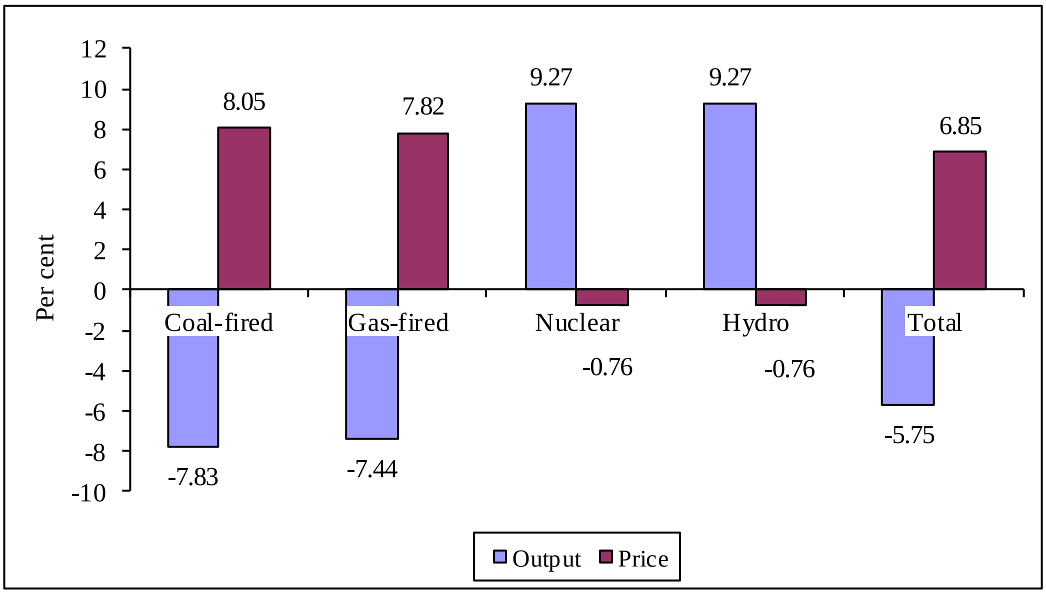
Source: Model simulation results.

Both higher consumer prices of energy intensive commodities and lower household income result in reductions in the household consumption of energy intensive commodities, such as chemical products, wood products, and transports. Moreover, a decline in household income leads to decreases in final consumption of non-energy intensive commodities, such as agricultural products, food products and textiles. In contrast, there are increases in final consumption of trade products, private services and minerals. The reason for this is a strong substitution effect since reductions of the consumer prices of these commodities are stronger compared to those of many other non-energy intensive commodities (Table 7.7).

#### 7.2.2.4 Technological Change in the Electricity Sector

As mentioned, the electricity sector is one of the most adversely affected sectors by the introduction of carbon taxation since the electricity sector is highly energy intensive. Figure 7.2 shows the changes in output and price of electricity from four power generation technologies.

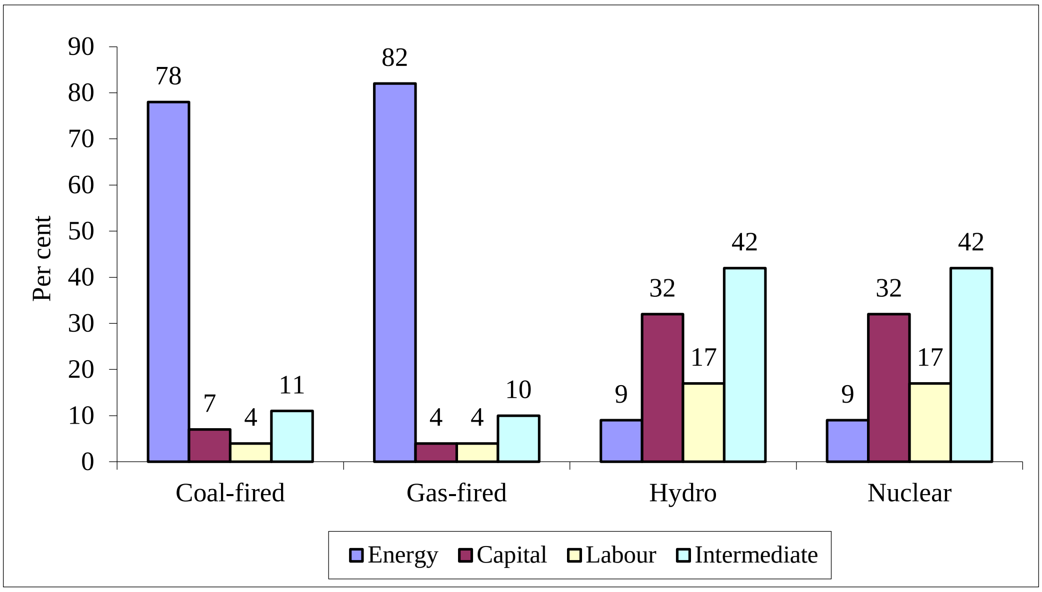
**Figure 7.2: Changes in Output and Price from Electricity Generation Technologies (per cent)**



Source: Model simulation results.

Introducing carbon taxes leads to a reduction in total production of electricity resulting from decreases in output from coal- and gas-fired electricity technologies with the reduction in output from coal-fired technologies being more pronounced compared to that from gas-fired technologies. This is because coal is the most carbon intensive energy input so that the burden of carbon taxation is mainly placed on coal. Coal-fired technologies, however, are assumed to be more capital intensive compared to gas-fired technologies (Figure 7.3).

**Figure 7.3: Cost Structure by Electricity Technologies (per cent of total)**



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

At the same time, carbon taxation leads to a reduction in capital costs, yet the effect of increased 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. This leads to a stronger reduction in output from coal-fired technologies as that from gas-fired technologies. In contrast, technologies such as nuclear and hydro become more profitable compared to thermal technologies so that output from nuclear and hydro technologies increases.

### 7.2.3 Carbon Dioxide Emissions

The magnitude of carbon taxation aims at a targeted reduction of overall $CO_2$ emissions by 10%. Reductions in $CO_2$ emissions are achieved via lower domestic demand for energy commodities used by industries and households. Table 7.11 reveals the changes in $CO_2$ emissions by sources and energy commodities.

**Table 7.11: Changes in $CO_2$ Emissions (giga gram)**

| | Coal | Crude oil | Natural gas | Petroleum products | Gas manufacture | Total |
|---|---:|---:|---:|---:|---:|---:|
| Coal | -94.5 | -0.03 | -0.02 | -0.01 | -0.1 | -94.6 |
| Crude oil | 0.01 | 25.4 | 57.0 | 4.4 | 14.4 | 101.3 |
| Natural gas | -0.001 | -51.3 | -520.7 | -13.3 | -1.0 | -586.2 |
| Petroleum products | n.a.[a] | n.a. | -400.6 | n.a. | -51.5 | -452.2 |
| Gas manufacture | -3.0 | -17.0 | n.a. | -37.2 | -231.9 | -289.1 |
| Electricity | -53,913.5 | -210.9 | -28,359.8 | -3,753.0 | -18,457.7 | -10,4694.9 |
| Wood products | -5.3 | -0.2 | 0.0 | -141.1 | -3.4 | -150.0 |
| Chemical products | -5.4 | -1.4 | -102.3 | -1,273.3 | -1,568.9 | -2,951.4 |
| Mineral products | -303.8 | -0.4 | -667.4 | -52.2 | -658.0 | -1,681.8 |
| Metals | -951.2 | -19.3 | -2,056.8 | -1,008.1 | -2,364.0 | -6,399.4 |
| Metal products | -4.7 | -0.1 | -25.7 | -37.8 | -73.8 | -142.2 |
| Electronic equipment | -1.0 | -0.03 | -0.003 | -17.1 | -22.7 | -40.8 |
| Transports | -36.6 | -6.2 | -4,847.8 | -3,297.1 | -4,838.9 | -13,026.7 |
| Machinery equipment | -35.7 | -0.3 | -106.5 | -13.5 | -347.6 | -503.5 |
| Water | -43.3 | -0.001 | -0.6 | -27.6 | -6.2 | -77.8 |
| Agriculture | -70.1 | -1.3 | -44.9 | -167.3 | -42.9 | -326.5 |
| Food products | -84.9 | -0.5 | -89.3 | -28.0 | -201.9 | -404.5 |
| Construction | -17.4 | -2.4 | -12.0 | -20.0 | -98.8 | -150.5 |
| Trade products | -161.2 | -0.002 | -61.8 | -126.2 | -112.5 | -461.7 |
| Transport equipment | -0.9 | -0.04 | -1.7 | 0.05 | -4.2 | -6.7 |
| Private services | -53.9 | -5.8 | -84.4 | -331.9 | -258.1 | -734.2 |
| Public services | -327.6 | -0.001 | -44.1 | -81.0 | -687.7 | -1,140.4 |
| Minerals | -0.3 | -0.2 | -3.5 | -1.6 | -2.1 | -7.7 |
| Textiles | -6.8 | -0.2 | -4.6 | -0.9 | -22.6 | -35.2 |
| Paper products | -1.1 | 0.0003 | -6.0 | 0.6 | -72.2 | -78.7 |
| Households | -3,099.7 | n.a. | -719.5 | 174.7 | -17,267.1 | -20,911.6 |
| **Total** | -59,221.9 | -292.2 | -38,103.0 | -10,248.5 | -47,381.4 | -155,247.0 |

[a] n.a. no $CO_2$ emissions are recorded in the database from usage of coal crude oil, petroleum products by the petroleum product sectors as well as from usage of natural gas by the gas manufacture sector.

Source: Model simulation results.

The main results are summarized as follows:

1) The total reduction of $CO_2$ emissions from coal accounts for 59,222 Giga grams, which is mainly achieved via reductions in demand for coal used by the electricity sector (53,914 Giga grams) and households (3,010 Giga grams).

2) The total reduction of $CO_2$ emissions from gas manufacture accounts for 47,381 Giga grams, which is mainly achieved via reductions in demand for gas manufacture used by the electricity sector (18,458 Giga grams) and households (17,267 Giga grams).

3) The total reduction of $CO_2$ emissions from natural gas accounts for 38,103 Giga grams, which is mainly achieved via reductions in demand for natural gas used by the electricity sector (28,360 Giga grams) and transports (4,848 Giga grams).

4) The total reduction of $CO_2$ emissions from petroleum products accounts for 10,249 Giga grams, which is mainly achieved via reductions in demand for petroleum products used by transports (3,297 Giga grams), the electricity sector (3,753 Giga gram), and the chemical products sector (1,273 Giga grams).

5) The total reduction of $CO_2$ emissions from crude oil accounts 292 Giga grams, which is mainly achieved via a reduction in demand for crude oil used by the electricity sector (211 Giga grams).

As shown in Table 7.12, the reduction of $CO_2$ emissions is mainly achieved via decreases in energy demand by the largest domestic consumers of energy, such as electricity, transports, chemical products, metals, and households.

**Table 7.12: Shares of Reduction in $CO_2$ Emissions by Sources and Changes in Energy Intensity (per cent)**

| | Baseline shares of $CO_2$ emission | Shares of reductions in $CO_2$ emissions | Energy intensity |
|---|---|---|---|
| Coal | 0.1 | 0.06 | -0.67 |
| Crude oil | 1.1 | -0.07 | 0.29 |
| Natural gas | 1.6 | 0.38 | -0.39 |
| Petroleum products | 1.5 | 0.29 | 0.01 |
| Gas manufacture | 0.1 | 0.19 | -4.09 |
| Electricity | 55.1 | 67.44 | -3.15 |
| Wood products | 0.1 | 0.10 | -2.75 |
| Chemical products | 2.2 | 1.90 | -1.92 |
| Mineral products | 1.4 | 1.08 | -4.47 |
| Metals | 4.0 | 4.12 | -3.29 |
| Metal products | 0.1 | 0.09 | -4.44 |
| Electronic equipment | 0.04 | 0.03 | -3.72 |
| Transports | 13.2 | 8.39 | -3.26 |
| Machinery equipment | 0.3 | 0.32 | -4.75 |
| Water | 0.1 | 0.05 | -4.55 |
| Agriculture | 1.1 | 0.21 | -2.38 |
| Food products | 0.4 | 0.26 | -3.60 |
| Construction | 0.3 | 0.10 | -2.83 |
| Trade products | 0.6 | 0.30 | -3.33 |
| Transport equipment | 0.004 | 0.004 | -3.50 |
| Private services | 1.5 | 0.47 | -2.77 |
| Public services | 1.0 | 0.73 | -4.02 |
| Minerals | 0.01 | 0.005 | -3.86 |
| textiles | 0.02 | 0.02 | -4.38 |
| Paper products | 0.1 | 0.05 | -5.35 |
| Households | 14.1 | 13.47 | n.a. |
| **Total** | **100** | **100** | **n.a.** |

Source: Model simulation results.

For example, a reduction in energy demand by the electricity sector is responsible for 67.4% of the overall reduction in $CO_2$ emissions, followed by households (13.5%), transports (8.4%). In addition, the electricity sector is also a large domestic contributor of non $CO_2$ GHG emissions as well as local air pollutions, such as nitrogen oxides ($NO_x$), sulphur dioxide ($SO_2$), and carbon monoxide (CO). According to the Fifth National Report of Russian Federation (UNFCCC, 2010a), the power generation sector produces about 81% of total GHG[37] emissions among all industries in Russia. Therefore, introducing carbon taxes will also lead to reductions in other emissions. 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

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[37] GHG states for greenhouse gas emissions, which include direct greenhouse gases such as $CO_2$ (carbon dioxide), $CH_4$ (methane), $N_2O$ (nitrous oxide), PFCs (perfluorocarbons), HFCs (hydro fluorocarbons), and $SF_6$ (sulphur hexafluoride).

(Bashmakov, 2009). Hence, the power generation sector is expected to play the crucial role in Russian environmental policy.

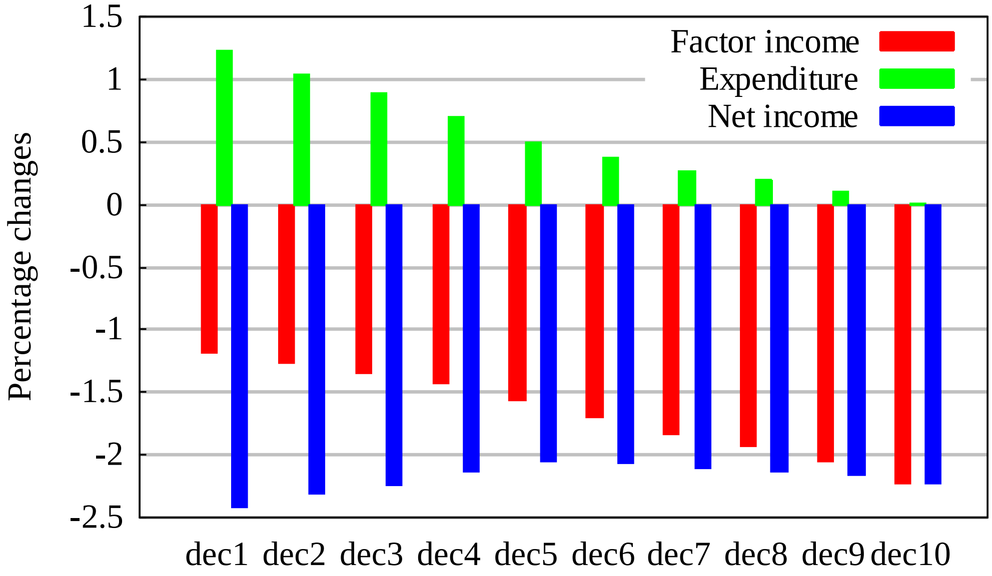
Carbon taxation on households and industries allows an avoidance of strong sectoral carbon leakages. For example, under carbon taxation on industries only, the domestic price level of energy commodities used by households would decrease. This would result in an increase in final consumption. A similar 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 both households and industries take the burden of carbon taxation.

**Energy intensity.** Reductions in demand for energy inputs are mainly associated with lower production. Nevertheless, the decreased demand for energy inputs used by industries is also achieved via substitution effects. In the presence of inter-fuel as well as factor-fuel substitutions, industries substitute energy inputs for less expensive production factors, such as capital and labour. Table 7.12 shows the changes in the sectoral energy intensity. The sectoral energy intensity is calculated by dividing the amount of total energy consumed by output. Negative (positive) values indicate decreases (increases) in energy intensity in per cent. According to the results, changes in energy intensity differ by sector, depending on initial energy and factor intensity. For example, the energy intensity of the paper products sector decreases by 5.35%, which means that the transport sector requires 5.35% less energy to produce a unit of output. The maximum reduction of energy intensity among sectors via substitution effects does not exceed 5.35%. In contrast, the energy intensity of crude oil and petroleum products sectors is slightly increased because of increasing demand for energy inputs by these sectors – carbon taxes are not imposed on energy inputs used by the crude oil and petroleum product sectors. The key factors in determining the magnitude of a reduction in energy intensity are elasticities of inter-fuel and factor-fuel substitutions as well as factor endowment. For example, under a Leontief nesting structure, the energy intensity would be constant since a Leontief nesting structure does not allow any substitution possibility in production. Despite high elasticities of substitution, reductions in energy intensity can also be limited by fixed factor supply. Furthermore, a reduction in energy intensity can be achieved through an adoption of new more energy efficient technologies.

### 7.2.4 Carbon Taxation and Income Equity

To examine the distributional effects of carbon taxes, a micro-accounting approach is used as discussed in Section 6.1.3. Disaggregated factor income and consumption expenditure categories by decile are multiplied by relative changes in factor and commodity prices. Figure 7.4 illustrates the relative changes in total factor income, total consumption expenditure and net income by decile resulting from the introduction of carbon taxes compensated by an increase in lump-sum transfers.

**Figure 7.4: Changes in Total Factor Income, Total Consumption Expenditures and Net Income[a] by Decile (per cent)**



Source: Model simulation results.

As shown in Figure 7.4, the uses-side incidence of carbon taxes is definitely regressive. Relative increases in consumption expenditures by poor households are larger compared to those by rich households as indicated by the green columns. This is because poor households spend more on consumption of coal, electricity, and gas relative to rich households, whereas the consumption share of petroleum products is larger by rich households. Moreover, the relative increase in the price of petroleum products is smaller compared to those of other energy inputs.

On the other hand, the source-side incidence of carbon taxes is quite progressive so that rich household groups are more adversely affected by lower factor prices than poor households. This is because the income share from capital and natural resources is significantly larger by rich households compared to that by poor households. At the same time, reductions in the returns to capital and natural resources are more pronounced than reductions in gross wages. Overall, the net income of poor households' decreases stronger compared to that of rich households as indicated by the blue columns since the regressive effect of the uses-side incidence of carbon taxes is more pronounced compared to the progressive effect of the source-side incidence.

Increase in lump-sum transfers as well as changes in savings rates are not taken into account in this analysis. Nevertheless, the revenue-recycling policy can significantly affect the income distribution. A distribution of revenues from carbon taxes in favour of poor households can increase progressivity of carbon taxation, thereby alleviating income inequality in Russia.

## 7.3 Substituting Carbon Taxes for Labour Taxes under Perfect Competition

### 7.3.1 Macroeconomic and Fiscal Effects

#### 7.3.1.1 Macroeconomic Effects

Table 7.13 shows the macroeconomic effects of two policy simulation experiments: (1) an introduction of carbon taxes compensated by an increase in lump-sum transfers (CT_HS) and (2) an introduction of carbon taxes compensated by a reduction in tax rates on labour income (CT_LT) under perfect competition in output markets. Compared to a CT_HS, substituting carbon taxes for labour taxes leads to small welfare gains measured by an EV of 0.23% of base household expenditure.

**Table 7.13: Macroeconomic Effects**

| | **Changes in million USD** | | **Changes in per cent** | |
|---|---|---|---|---|
| | **CT_HS** | **CT_LT** | **CT_HS** | **CT_LT** |
| Equivalent variation | -2,176 | 668 | -0.75 | 0.23 |
| Exchange rate | n.a. | n.a. | 0.08 | 0.11 |
| Real GDP at value added | -2,399 | -81 | -0.43 | -0.01 |
| Rate of lump-sum transfers | n.a. | n.a. | 10.78 | fixed |
| Rate of labour taxes | n.a. | n.a. | fixed | -15.97 |
| **Household expenditure:** | -1,278 | 1,616 | -0.44 | 0.56 |
| Household income | -7,565 | 1,375 | -2.05 | 0.37 |
| Household savings | 224 | 43 | 0.14 | 0.03 |
| Lump-sum transfers | 6,511 | 284 | 8.51 | 0.37 |

Source: Model simulation results.

Moreover, CT_LT results in an increase in household expenditures – household income minus savings and plus lump-sum transfers – because of both higher household income and a reduction in the household savings rate (by 0.34%). According to the model closures, government savings and investment are fixed, which implies an investment driven closure. Due to a higher household income, the household savings rate decreases to match fixed investment. Alternatively, if the household savings rate is fixed, investment in real terms would increase because of higher household income, but increase in final consumption would be less pronounced than that is under investment driven closure.

#### 7.3.1.2 Factor Markets

Table 7.14 shows the changes in household income as well as factor supply, and factor prices under a CT_HS and CT_LT. Household income is defined as income from capital, labour, land, and natural resources minus taxes on factor income and a fiscal depreciation of capital. Compared to a CT_HS, substituting carbon taxes results in an increase in household income. There is an increase in labour income via lower taxes on labour income and higher labour supply as well as an increase in income from land via an increase in the supply of land. Both tax rates on income from unskilled and skilled labour are reduced each by approximately 15.97%, which leads to increases in the supply of unskilled and skilled labour. An increase in labour supply indicates the occurrence of an employment double dividend, where substituting environmental taxes for labour taxes leads to a reduction in unemployment (Bovenberg and van der Ploeg, 1994). Moreover, CT_LT results in an increase in domestic production of agricultural products, which is associated with increasing demand for land. Given the assumption of perfectly elastic supply of land, land income increases because of higher land supply.

**Table 7.14: Changes in Factor Income, Factor Prices, and Factor Supply**

| | **Household income (million USD)** | | **Factor prices (per cent)** | | **Factor supply (per cent)** | |
|---|---|---|---|---|---|---|
| | **CT_HS** | **CT_LT** | **CT_HS** | **CT_LT** | **CT_HS** | **CT_LT** |
| Land | -28 | 40 | fixed | fixed | -0.42 | 0.62 |
| Unskilled labour | -1,343 | 4,270 | -1.11 | -2.05 | -0.34 | 1.04 |
| Skilled labour | -527 | 1,954 | -0.94 | -2.12 | -0.28 | 1.02 |
| Capital | -5,157 | -4,401 | -2.59 | -2.21 | fixed | fixed |
| Natural resources | -510 | -489 | -7.41 | -5.98 | fixed | fixed |
| **Total** | -7,565 | 1,375 | **n.a.** | **n.a.** | **n.a.** | **n.a.** |

Source: Model simulation results.

CT_LT leads also to decreases in income from capital and natural resources, yet these are less pronounced compared to those under a CT_HS. Reductions in the returns to capital and natural resources result from lower demand for these factors. Supply of capital and natural resources is fixed. Therefore, the burden of carbon taxes is partially borne by capital and natural resources in terms of lower factor income. In other words, increases in energy costs do not fully pass on to final consumers, yet these are partially absorbed by lower factor prices. As mentioned, this indicates a tax-shifting effect between labour, capital and natural resources (de Mooij and Bovenberg, 1998; Bento and Jacobsen, 2007; Bovenberg and van der Ploeg, 1998; Fraser and Waschik, 2010). It should be noted that a strong tax-shifting effect is a necessary condition for the occurrence of a strong double dividend (de Mooij, 2000).

### 7.3.1.3 Government Budget

Table 7.15 shows the changes in government expenditures and revenues from trade and domestic taxes under a CT_HS and CT_LT. Compared to a CT_HS, substituting carbon taxes for labour taxes leads to higher increases in the revenues from export and carbon taxes, whereas reductions in the revenues from taxes on consumption, capital income, imports, mineral resources extraction, and social security contributions are less pronounced than those under a CT_HS. Furthermore, there is an increase in the total revenue from the land tax because of increased supply of land.

**Table 7.15: Changes in Government Revenues and Expenditures from Trade and Domestic Taxes (million USD)**

| | CT_HS | CT_LT |
|---|---|---|
| **Government revenues:** | 5,850.2 | -867.1 |
| Export taxes | 499.0 | 501.9 |
| Import taxes | -55.6 | -3.9 |
| Carbon taxes | 7,977.0 | 8,373.5 |
| Consumption taxes | -1,306.7 | -1,050.1 |
| Taxes on unskilled labour income | -478.3 | -5,570.3 |
| Taxes on skilled labour income | -187.8 | -2,611.8 |
| Social security contributions from unskilled labour | -46.2 | -33.1 |
| Social security contributions from skilled labour | -18.2 | -16.8 |
| Capital taxes | -488.2 | -417.7 |
| Mineral resource extraction taxes | -43.1 | -41.3 |
| Land tax | -1.8 | 2.6 |
| **Government expenditures:** | 6,505.9 | 285.3 |
| Lump-sum transfers | 6,511.0 | 284.4 |
| Production subsidies | -5.0 | 0.8 |

Source: Model simulation results.

**Export taxes.** Table 7.16 reveals the changes in revenues from export taxes and export supply under a CT_HS and CT_LT. Due to a higher depreciation of the currency and lower labour costs, substituting carbon taxes for labour taxes leads to larger (smaller) increases (decreases) in export supplies of most commodities compared to those under a CT_HS. This is because domestic producers of energy and non-energy intensive commodities become more competitive under a CT_LT compared to that under a CT_HS. Furthermore under a CT_LT, there is an increase in the export supply of textiles and machinery equipment, whereas under a CT_HS it is reduced. Overall, the increase in the total revenue from export taxes is slightly more pronounced under a CT_LT compared to that under a CT_HS.

**Table 7.16: Changes in Revenues from Export Taxes**

| | **Changes in revenues from export taxes (million USD)** | | **Changes in export supply (per cent)** | |
|---|---|---|---|---|
| | **CT_HS** | **CT_LT** | **CT_HS** | **CT_LT** |
| Coal | 2.07 | 2.20 | 7.52 | 7.96 |
| Crude oil | 357.62 | 350.14 | 1.93 | 1.85 |
| Natural gas | 335.23 | 330.93 | 24.54 | 24.17 |
| Petroleum products | 34.09 | 31.97 | 1.37 | 1.24 |
| Wood products | -70.63 | -67.95 | -13.27 | -12.80 |
| Chemical products | -57.56 | -54.51 | -8.26 | -7.86 |
| Mineral products | -1.21 | -1.00 | -2.90 | -2.45 |
| Metals | -112.58 | -110.01 | -6.43 | -6.32 |
| Metal products | -0.71 | -0.46 | -3.09 | -2.07 |
| Electronic equipment | -0.23 | -0.19 | -3.91 | -3.24 |
| Machinery equipment | -0.78 | 0.14 | -1.13 | 0.08 |
| Agricultural products | 0.01 | 0.04 | 0.44 | 1.90 |
| Transport equipment | 0.41 | 1.14 | 0.59 | 1.75 |
| Minerals | 3.75 | 4.34 | 2.19 | 2.51 |
| Textiles | -0.08 | 1.79 | -0.14 | 1.49 |
| Paper products | 9.67 | 13.32 | 2.83 | 3.89 |
| **Total** | **499.04** | **501.87** | **n.a.** | **n.a.** |

Source: Model simulation results.

**Import taxes.** Table 7.17 shows the changes in revenues from import tariffs and import demand under a CT_HS and CT_LT. Compared to a CT_HS, substituting carbon taxes leads to smaller (higher) decreases (increases) in import demand for most commodities, despite a stronger depreciation of the currency under a CT_LT. This is due to increased household income under a CT_LT, while under a CT_HS it decreases. Furthermore, there are increases in import demand for chemical products and electronic equipment, whereas under a CT_HS import demand for these commodities is reduced. The reason for this is an increase in household income under a CT_LT. Overall, the total revenue from import tariffs is decreased by 3.88 million USD under a CT_LT, whereas under a CT_HS it is 55.59 million USD.

**Table 7.17: Changes in Revenues from Import Tariffs**

| | Changes in revenues from import tariffs (million USD) | | Changes in import demand (per cent) | |
|---|---|---|---|---|
| | CT_HS | CT_LT | CT_HS | CT_LT |
| Coal | -0.19 | -0.20 | -22.73 | -23.23 |
| Crude oil | -0.0002 | -0.0002 | -5.23 | -5.03 |
| Natural gas | -0.0002 | -0.0002 | -25.04 | -24.81 |
| Petroleum products | -0.15 | -0.14 | -4.28 | -3.98 |
| Electricity | 0.39 | 0.47 | 3.50 | 4.26 |
| Wood products | 7.23 | 9.52 | 2.12 | 2.78 |
| Chemical products | -1.26 | 6.30 | -0.18 | 0.41 |
| Mineral products | 0.68 | 1.03 | 0.20 | 0.31 |
| Metals | 0.57 | 1.69 | 0.22 | 0.77 |
| Metal products | -1.87 | -0.91 | -0.63 | -0.38 |
| Electronic equipment | -0.17 | 1.94 | -0.11 | 0.25 |
| Machinery equipment | -8.51 | -7.99 | -0.56 | -0.57 |
| Agricultural products | -3.45 | -1.36 | -1.18 | -0.55 |
| Food products | -17.37 | -4.10 | -1.18 | -0.37 |
| Transport equipment | -12.08 | -4.65 | -0.89 | -0.43 |
| Minerals | -0.65 | -0.60 | -4.32 | -4.03 |
| Textiles | -14.47 | -2.12 | -1.08 | -0.26 |
| Paper products | -4.27 | -2.76 | -1.80 | -1.23 |
| **Total** | **-55.59** | **-3.88** | **n.a.** | **n.a.** |

Source: Model simulation results.

**Domestic taxes.** Substituting carbon taxes for labour taxes leads to lower reductions in the returns to capital and natural resources compared to when revenues from carbon taxes are returned to households in lump-sum form. As a result, decreases in the revenues from taxes on capital and mineral resource extraction are less pronounced compared to those under a CT_HS. Furthermore, there are smaller reductions in social security contributions from unskilled and skilled labour because of increased labour supply. Finally, an increase in household income under a CT_LT results in a smaller reduction in the total revenue from consumption taxes than that under a CT_HS.

## 7.3.2 Sectoral Effects

### 7.3.2.1 Producer and Consumer Prices

Table 7.18 shows the changes in activity prices under a CT_HS and CT_LT.  As mentioned, compared to a CT_HS, substituting carbon taxes for labour taxes leads to smaller reductions in the returns to capital and natural resources. As a result, increases (decreases) in the activity prices of capital-energy aggregate (PVKE) are more (less) pronounced than those under a CT_HS (Column 3 of Table 7.18). On the other hand, there are stronger reductions in labour costs under a CT_LT than those under a CT_HS because of higher reductions in wages. Therefore, the key factor is the capital-labour intensive of sectors. Substituting carbon taxes for labour taxes leads to larger (smaller) decreases (increases) in the activity prices of value added-energy aggregate (PVAE) of labour intensive sectors, such machinery equipment, agricultural products and food products (Column 2 of Table 7.18). As a result, reductions in total average production costs (PX) in most labour intensive sectors are more pronounced under a CT_LT compared to those under a CT_HS (Column 1 of Table 7.18). Moreover, there are reductions in average production costs in the water and machinery equipment sectors, whereas under a CT_HS average production costs in these sectors increase.

**Table 7.18: Changes in Activity Prices (per cent)**

| | **(1)** | | **(2)** | | **(3)** | |
|---|---|---|---|---|---|---|
| | **PX** | | **PVAE** | | **PVKE** | |
| | **CT_HS** | **CT_LT** | **CT_HS** | **CT_LT** | **CT_HS** | **CT_LT** |
| Coal | -4.14 | -4.23 | -7.76 | -7.90 | 4.99 | 5.44 |
| Crude oil | -0.48 | -0.42 | -0.55 | -0.46 | -1.79 | -1.40 |
| Natural gas | -2.45 | -2.38 | -3.73 | -3.69 | 1.47 | 1.94 |
| Petroleum products | -1.06 | -0.94 | -1.07 | -0.95 | -1.07 | -0.91 |
| Gas manufacturing | -0.36 | -0.64 | -0.31 | -0.77 | 0.82 | 1.20 |
| Electricity | 6.85 | 7.27 | n.a.a) | n.a. | n.a. | n.a. |
| Wood products | 2.81 | 2.87 | 4.67 | 4.80 | 6.04 | 6.45 |
| Chemical products | 1.38 | 1.44 | 2.20 | 2.28 | 2.96 | 3.31 |
| Mineral products | 0.94 | 0.88 | 1.94 | 1.79 | 4.03 | 4.47 |
| Metals | 0.98 | 1.07 | 1.79 | 1.91 | 2.53 | 2.94 |
| Metal products | 0.61 | 0.48 | 0.61 | 0.21 | 2.86 | 3.27 |
| Electronic equipment | 0.77 | 0.74 | 1.56 | 1.46 | 2.99 | 3.39 |
| Transports | 0.40 | 0.39 | 0.88 | 0.87 | 1.70 | 2.11 |
| Machinery equipment | 0.20 | -0.03 | 0.06 | -0.45 | 2.16 | 2.56 |
| Water | 0.09 | -0.21 | 0.36 | -0.08 | 2.37 | 2.77 |
| Agricultural products | -0.43 | -0.65 | -0.44 | -0.73 | 0.78 | 1.17 |
| Food products | -0.50 | -0.58 | -0.55 | -0.61 | -0.30 | 0.09 |
| Construction | -0.75 | -0.85 | -1.71 | -1.90 | -2.16 | -1.78 |
| Trade products | -1.66 | -1.51 | -2.29 | -2.06 | -2.44 | -2.06 |
| Transport equipment | -0.22 | -0.32 | -1.50 | -2.08 | -2.48 | -2.10 |
| Private services | -1.16 | -1.29 | -1.46 | -1.62 | -1.71 | -1.33 |
| Public services | -0.70 | -1.25 | -0.87 | -1.67 | -0.31 | 0.08 |
| Minerals | -1.73 | -1.70 | -2.66 | -2.61 | -2.55 | -2.17 |
| Textiles | -0.15 | -0.31 | -0.10 | -0.50 | 1.28 | 1.67 |
| Paper products | -0.87 | -0.92 | -1.83 | -1.87 | -2.17 | -1.78 |

[a] Changes in the activity prices of electricity generation differ by technology.

Source: Model simulation results.

Changes in production costs (PX) determine, *inter alia*, changes in producer prices (PD) (Table 7.19). Consumer prices (PQD) are weight average of producer prices (PD) and import prices (PM). Substituting carbon taxes for labour taxes results in a larger increase in import prices because of a stronger depreciation of the currency compared to that under a CT_HS.

Nevertheless under a CT_LT, reductions of production costs of most non-energy intensive sectors are more pronounced, which leads to stronger decreases in the consumer prices of non-energy intensive commodities as well as lower increases in the consumer prices of some energy intensive commodities compared to those under a CT_HS (Column 1 of Table 7.19).

**Table 7.19: Changes in Producer and Consumer Prices (per cent)**

| | (1) | | (2) | | (3) | |
|---|---|---|---|---|---|---|
| | Consumer price | | Producer price | | Competitiveness indicator | |
| | CT_HS | CT_LT | CT_HS | CT_LT | CT_HS | CT_LT |
| Coal | 22.38 | 23.64 | -7.12 | -7.31 | 7.75 | 8.01 |
| Crude oil | 5.92 | 6.37 | -1.24 | -1.15 | 1.33 | 1.28 |
| Natural gas | 13.16 | 14.01 | -2.45 | -2.38 | 2.59 | 2.55 |
| Petroleum products | 2.55 | 2.89 | -1.37 | -1.22 | 1.46 | 1.35 |
| Gas manufacturing | 19.44 | 20.06 | -0.47 | -0.83 | 0.55 | 0.95 |
| Electricity | 6.84 | 7.25 | 6.91 | 7.33 | -6.39 | -6.72 |
| Wood products | 2.59 | 2.65 | 4.59 | 4.66 | -4.32 | -4.35 |
| Chemical products | 1.34 | 1.40 | 2.42 | 2.50 | -2.28 | -2.33 |
| Mineral products | 0.82 | 0.78 | 0.99 | 0.93 | -0.91 | -0.81 |
| Metals | 1.65 | 1.79 | 1.91 | 2.06 | -1.80 | -1.91 |
| Metal products | 0.49 | 0.40 | 0.73 | 0.56 | -0.65 | -0.44 |
| Electronic equipment | 0.24 | 0.26 | 0.92 | 0.88 | -0.83 | -0.76 |
| Transports | 0.42 | 0.40 | 0.46 | 0.44 | -0.39 | -0.33 |
| Machinery equipment | 0.16 | 0.01 | 0.22 | -0.05 | -0.14 | 0.16 |
| Water | 0.09 | -0.21 | 0.09 | -0.21 | -0.01 | 0.32 |
| Agricultural products | -0.42 | -0.63 | -0.47 | -0.71 | 0.55 | 0.83 |
| Food products | -0.41 | -0.48 | -0.55 | -0.64 | 0.63 | 0.76 |
| Construction | -0.73 | -0.82 | -0.76 | -0.87 | 0.84 | 0.99 |
| Trade products | -1.65 | -1.50 | -1.68 | -1.53 | 1.78 | 1.66 |
| Transport equipment | -0.13 | -0.18 | -0.32 | -0.46 | 0.39 | 0.58 |
| Private services | -1.07 | -1.19 | -1.25 | -1.39 | 1.34 | 1.53 |
| Public services | -0.68 | -1.22 | -0.70 | -1.26 | 0.78 | 1.39 |
| Minerals | -2.14 | -2.11 | -2.58 | -2.54 | 2.72 | 2.73 |
| Textiles | -0.03 | -0.08 | -0.20 | -0.40 | 0.28 | 0.52 |
| Paper products | -0.76 | -0.81 | -1.24 | -1.33 | 1.33 | 1.46 |

Source: Model simulation results.

Furthermore, most domestically produced energy commodities as well as non-energy intensive commodities, such as agricultural products, food products, and textiles, become more competitive under a CT_LT compared to that when revenuers from carbon taxes are returned to households in lump-sum form. This is demonstrated with higher percentage increases in the ratio between import and domestic prices in Colum 3 of Table 7.19.

### 7.3.2.2 Production and Consumption

Table 7.20 and 7.21 reveals the sectoral effects under a CT_HS and CT_LT.

**Table 7.20: Changes in Domestic Consumption, Domestic and Import Demand (per cent)**

| | Domestic consumption | | Domestic demand | | Import demand | |
|---|---|---|---|---|---|---|
| | **CT_HS** | **CT_LT** | **CT_HS** | **CT_LT** | **CT_HS** | **CT_LT** |
| **Energy sectors:** | | | | | | |
| Coal | -14.98 | -15.26 | -13.41 | -13.65 | -22.73 | -23.23 |
| Crude oil | -1.95 | -1.88 | -1.91 | -1.84 | -5.23 | -5.03 |
| Natural gas | -7.14 | -7.13 | -6.64 | -6.64 | -25.04 | -24.81 |
| Petroleum products | -2.81 | -2.63 | -2.81 | -2.62 | -4.28 | -3.98 |
| Gas manufacture | -13.55 | -13.37 | -13.55 | -13.37 | -14.21 | -14.52 |
| **Energy intensive sectors:** | | | | | | |
| Electricity | -5.55 | -5.32 | -5.64 | -5.42 | 3.50 | 4.26 |
| Wood products | -2.10 | -1.50 | -5.26 | -4.70 | 2.12 | 2.78 |
| Chemical products | -2.23 | -1.69 | -3.92 | -3.42 | -0.18 | 0.41 |
| Mineral products | -0.87 | -0.65 | -1.11 | -0.86 | 0.20 | 0.31 |
| Metals | -2.54 | -2.18 | -2.97 | -2.64 | 0.22 | 0.77 |
| Metal products | -1.40 | -0.91 | -1.83 | -1.20 | -0.63 | -0.38 |
| Electronic equipment | -0.54 | -0.15 | -2.29 | -1.75 | -0.11 | 0.25 |
| Transports | -1.22 | -0.65 | -1.26 | -0.69 | -0.90 | -0.38 |
| Machinery equipment | -0.73 | -0.38 | -0.84 | -0.25 | -0.56 | -0.57 |
| Water | -0.73 | -0.07 | -0.73 | -0.07 | -0.71 | -0.51 |
| **Non-energy intensive sectors:** | | | | | | |
| Agricultural products | -0.47 | 0.53 | -0.39 | 0.65 | -1.18 | -0.55 |
| Food products | -0.46 | 0.50 | -0.26 | 0.75 | -1.18 | -0.37 |
| Construction | -0.26 | -0.17 | -0.17 | -0.06 | -2.27 | -2.52 |
| Trade products | -0.36 | 0.23 | -0.33 | 0.25 | -1.99 | -1.31 |
| Transport equipment | -0.53 | 0.10 | -0.19 | 0.59 | -0.89 | -0.43 |
| Private services | -0.53 | 0.04 | -0.42 | 0.16 | -1.20 | -0.73 |
| Public services | -0.03 | 0.14 | -0.01 | 0.18 | -0.75 | -1.13 |
| Minerals | -3.35 | -3.06 | -3.15 | -2.86 | -4.32 | -4.03 |
| Textiles | -0.94 | 0.00 | -0.70 | 0.45 | -1.08 | -0.26 |
| Paper products | -0.57 | 0.13 | 0.14 | 0.92 | -1.80 | -1.23 |

Source: Model simulation results.

**Table 7.21: Changes in Domestic Production, Domestic and Export Supply (per cent)**

| | Domestic production | | Domestic supply | | Export supply | |
|---|---|---|---|---|---|---|
| | **CT_HS** | **CT_LT** | **CT_HS** | **CT_LT** | **CT_HS** | **CT_LT** |
| **Energy sectors:** | | | | | | |
| Coal | -5.11 | -5.07 | -13.41 | -13.65 | 7.52 | 7.96 |
| Crude oil | 0.30 | 0.28 | -1.91 | -1.84 | 1.93 | 1.85 |
| Natural gas | -1.94 | -1.99 | -6.64 | -6.64 | 24.54 | 24.17 |
| Petroleum products | -1.93 | -1.81 | -2.81 | -2.62 | 1.37 | 1.24 |
| Gas manufacture | -13.28 | -12.88 | -13.55 | -13.37 | -12.18 | -10.95 |
| **Energy intensive sectors:** | | | | | | |
| Electricity | -5.75 | -5.53 | -5.64 | -5.42 | -17.32 | -17.71 |
| Wood products | -8.46 | -7.94 | -5.26 | -4.70 | -13.27 | -12.80 |
| Chemical products | -5.85 | -5.39 | -3.92 | -3.42 | -8.26 | -7.86 |
| Mineral products | -1.22 | -0.96 | -1.11 | -0.86 | -2.90 | -2.45 |
| Metals | -4.74 | -4.52 | -2.97 | -2.64 | -6.43 | -6.32 |
| Metal products | -2.06 | -1.36 | -1.83 | -1.20 | -3.09 | -2.07 |
| Electronic equipment | -2.58 | -2.02 | -2.29 | -1.75 | -3.91 | -3.24 |
| Transports | -1.38 | -0.79 | -1.26 | -0.69 | -2.03 | -1.34 |
| Machinery equipment | -0.88 | -0.20 | -0.84 | -0.25 | -1.13 | 0.08 |
| Water | -0.73 | -0.06 | -0.73 | -0.07 | -0.75 | 0.58 |
| **Energy intensive sectors:** | | | | | | |
| Agricultural products | -0.33 | 0.74 | -0.39 | 0.65 | 0.44 | 1.90 |
| Food products | -0.18 | 0.84 | -0.26 | 0.75 | 0.68 | 1.89 |
| Construction | -0.13 | -0.02 | -0.17 | -0.06 | 1.53 | 1.92 |
| Trade products | -0.30 | 0.28 | -0.33 | 0.25 | 3.26 | 3.62 |
| Transport equipment | 0.00 | 0.88 | -0.19 | 0.59 | 0.59 | 1.75 |
| Private services | -0.24 | 0.37 | -0.42 | 0.16 | 2.27 | 3.25 |
| Public services | -0.01 | 0.19 | -0.01 | 0.18 | 1.55 | 2.98 |
| Minerals | -1.47 | -1.16 | -3.15 | -2.86 | 2.19 | 2.51 |
| Textiles | -0.60 | 0.64 | -0.70 | 0.45 | -0.14 | 1.49 |
| Paper products | 0.90 | 1.76 | 0.14 | 0.92 | 2.83 | 3.89 |

Source: Model simulation results.

**Energy commodities.** Substituting carbon taxes for labour taxes leads to reductions in consumption of domestically produced as well as imported energy inputs with relative decreases in demand for imported energy inputs being more pronounced compared to those of domestically produced. Moreover, the reduction in demand for coal stronger under a CT_LT compared to that under a CT_HS since other energy inputs are more labour intensive than coal. Furthermore, there are increases in export supplies of coal, natural gas, crude oil, and petroleum products.

**Energy intensive commodities.** Substituting carbon taxes for labour taxes leads to decreases in the total consumption of energy intensive commodities, such as electricity, wood products, and chemical products. Compared to a CT_HS, CT_LT results in smaller reductions in export supply as well as domestic demand for domestically produced energy intensive commodities. Under a CT_LT, increases (decreases) in import demand for energy intensive commodities are more (less) pronounced compared to those under a CT_HS due to higher household income. Moreover, under a CT_LT, there are increases in import demand for chemical products and electronic equipment, whereas under a CT_HS import demand for these commodities is reduced because of decreased household income.

**Non-energy intensive commodities.** Compared to a CT_HS, substituting carbon taxes for labour taxes leads to increases in demand for most domestically produced commodities, such as agriculture, food products, and trade products because of increased household income as well as lower consumer prices. Moreover, decreases in import demand for non-energy intensive commodities as well as increases in export supplies of non-energy intensive commodities are more pronounced under a CT_LT compared to those under a CT_HS. The reason for this is that domestically produced non-energy intensive commodities become more competitive in domestic and export markets under a CT_LT compared to that under a CT_HS because of decreased production costs.

#### 7.3.2.3 Final Consumption

Table 7.22 shows the changes in household consumption under a CT_HS and CT_LT. Compared to a CT_HS, substituting carbon taxes for labour taxes leads to smaller decreases in the household consumption of coal, natural gas, and gas manufacture, where the increase in final consumption of petroleum products is more pronounced. As a result of higher household income, decreases in final consumption of energy intensive commodities, such as electricity, wood products, and chemical products are also less under a CT_LT compared to those under a CT_HS. Furthermore, substituting carbon taxes for labour taxes leads to increases in household consumption of most non-energy intensive commodities, such as agriculture, food products, and private services because of higher household income.

**Table 7.22: Changes in Final Consumption (per cent)**

| | CT_HS | CT_LT |
|---|---|---|
| Coal | -15.99 | -15.85 |
| Natural gas | -9.14 | -8.74 |
| Petroleum products | 0.26 | 1.12 |
| Gas manufacturing | -13.92 | -13.34 |
| Electricity | -3.76 | -2.99 |
| Wood products | -3.41 | -2.52 |
| Chemical products | -2.21 | -1.32 |
| Mineral products | -1.71 | -0.71 |
| Metals | -2.51 | -1.69 |
| Metal products | -1.39 | -0.33 |
| Electronic equipment | -1.14 | -0.20 |
| Transports | -1.32 | -0.34 |
| Machinery equipment | -1.06 | 0.05 |
| Water | -0.99 | 0.27 |
| Agricultural products | -0.49 | 0.69 |
| Food products | -0.49 | 0.54 |
| Construction | -0.18 | 0.89 |
| Trade products | 0.76 | 1.59 |
| Transport equipment | -0.78 | 0.25 |
| Private services | 0.17 | 1.27 |
| Public services | -0.23 | 1.30 |
| Minerals | 1.27 | 2.22 |
| Textiles | -0.87 | 0.14 |
| Paper products | -0.14 | 0.88 |

Source: Model simulation results.

#### 7.3.2.4 Technological Change in the Electricity Sector

Substituting carbon taxes for labour taxes results in a larger increase in the producer price of electricity compared to that under a CT_HS, whereas the reduction in output is less pronounced (Table 7.23). This is because under a CT_LT the economy is less adversely affected by carbon taxes so that the reduction in final consumption of electricity as well as reductions in demand for electricity by some electricity-intensive sectors is less compared to those under a CT_HS. Furthermore, due to greater decreases in labour costs, increases in output from nuclear and hydro are higher under a CT_LT compared to those under a CT_HS.

**Table 7.23: Changes in Output and Production Costs by Electricity Generation Technologies under a CT_HS and CT_LT (per cent)**

| | Output | | Prices | |
|---|---|---|---|---|
| | **CT_HS** | **CT_LT** | **CT_HS** | **CT_LT** |
| Coal-fired | -7.83 | -7.79 | 8.05 | 8.58 |
| Gas-fired | -7.44 | -7.27 | 7.82 | 8.27 |
| Nuclear | 9.27 | 10.38 | -0.76 | -0.76 |
| Hydro | 9.27 | 10.38 | -0.76 | -0.76 |
| **Total** | **-5.75** | **-5.53** | **6.85** | **7.27** |

Source: Model simulation results.

### 7.3.3 Carbon Dioxide Emissions

According to the policy simulation, the overall $CO_2$ emissions are reduced by 10%. Table 7.24 shows the shares of reductions in $CO_2$ by industries and the household under a CT_HS and a CT_LT. The results are quite similar. Under both revenue recycling strategies, the overall reduction in $CO_2$ is mainly achieved by the electricity sector, households, and transports, yet the reduction in $CO_2$ by households is relatively less pronounced under a CT_LT compared to that under a CT_HS because of increased household income.

**Table 7.24: Shares of Reduction in $CO_2$ Emissions by Sources and Changes in Energy Intensity (per cent)**

| | Shares of reductions in $CO_2$ emissions | | Energy intensity | |
|---|---|---|---|---|
| | **CT_HS** | **CT_LT** | **CT_HS** | **CT_LT** |
| Coal | 0.06 | 0.06 | -0.67 | -0.75 |
| Crude oil | -0.07 | -0.05 | 0.29 | 0.21 |
| Natural gas | 0.38 | 0.40 | -0.39 | -0.46 |
| Petroleum products | 0.29 | 0.28 | 0.01 | -0.04 |
| Gas manufacture | 0.19 | 0.19 | -4.09 | -5.01 |
| Electricity | 67.44 | 68.00 | -3.15 | -3.37 |
| Wood products | 0.10 | 0.09 | -2.75 | -3.10 |
| Chemical products | 1.90 | 1.87 | -1.92 | -2.24 |
| Mineral products | 1.08 | 1.15 | -4.47 | -5.12 |
| Metals | 4.12 | 4.21 | -3.29 | -3.65 |
| Metal products | 0.09 | 0.09 | -4.44 | -5.26 |
| Electronic equipment | 0.03 | 0.03 | -3.72 | -4.27 |
| Transports | 8.39 | 8.52 | -3.26 | -3.90 |
| Machinery equipment | 0.32 | 0.34 | -4.75 | -5.69 |
| Water | 0.05 | 0.05 | -4.55 | -5.47 |
| Agriculture | 0.21 | 0.11 | -2.38 | -2.49 |
| Food products | 0.26 | 0.25 | -3.60 | -4.09 |
| Construction | 0.10 | 0.11 | -2.83 | -3.58 |
| Trade products | 0.30 | 0.29 | -3.33 | -3.62 |
| Transport equipment | 0.004 | 0.004 | -3.50 | -4.47 |
| Private services | 0.47 | 0.49 | -2.77 | -3.43 |
| Public services | 0.73 | 0.85 | -4.02 | -5.36 |
| Minerals | 0.005 | 0.005 | -3.86 | -3.96 |
| Textiles | 0.02 | 0.02 | -4.38 | -5.22 |
| Paper products | 0.05 | 0.05 | -5.35 | -5.91 |
| Household | 13.47 | 12.59 | n.a. | n.a. |
| **Total** | **100** | **100** | **n.a.** | **n.a.** |

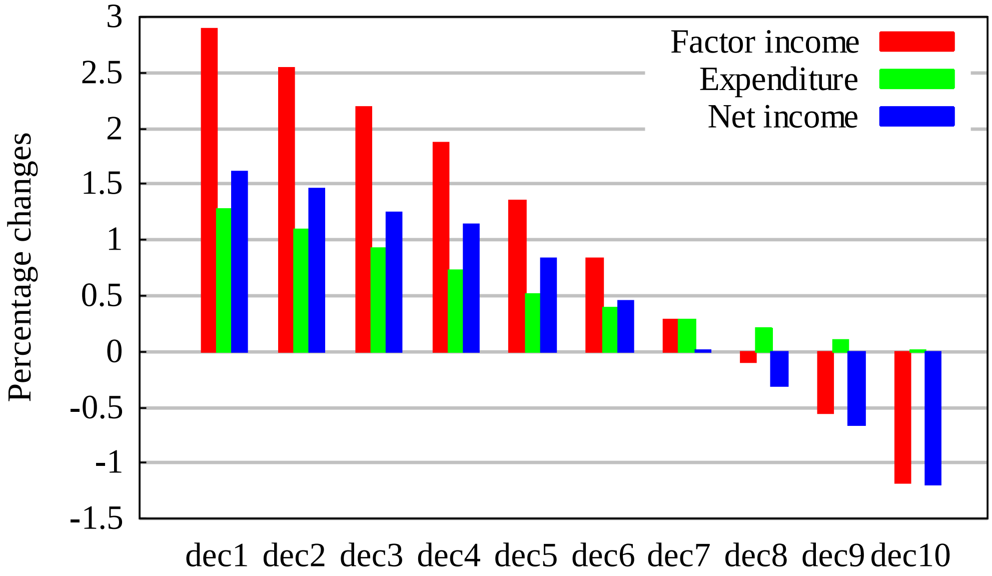
* Gg states for Giga gram

Source: Model simulation results.

### 7.3.4 Carbon Taxes and Income Equity

Distributional effects of carbon taxation are investigated by using simple micro-accounting approach. Distributed factor income and consumption expenditure among ten deciles are multiplied by relative changes in factor and commodity prices (Section 6.1.3). Figure 7.5 shows the relative changes in total factor income, total consumption expenditure and net income by decile resulting from carbon taxation.

**Figure 7.5: Changes in Total Factor Income, Total Consumption Expenditures and Net Income[a] by Decile (per cent)**



**dec1** represents the poorest ten per cent of the population, **dec10** the richest ten per cent.

[a] Net income is the aggregated effect of expenditure and factor income changes.

Source: Model simulation results.

Introducing carbon taxes leads to increasing total consumption expenditures for all household groups with poor households being more affected in relative terms because their expenditure shares on energy consumption – gas, electricity, and coal – are larger. Therefore, carbon taxes *per se* have a regressive impact on income distribution. On the other hand, revenues from carbon taxes are compensated by a reduction in taxes on labour income. Poor households benefit more in relative terms from this tax reduction, since labour income has a larger share in total factor income for poor than for rich households. Moreover, the richest household groups (from decile 8 to decile 10) face even reductions in factor income because of lower returns to capital and natural resources – the main income source of rich households. Overall, substituting carbon taxes for labour taxes results in increases in net income of low and middle income household groups (from decile 1 to decile 6), with the relative increases in net income being especially large for the poorest households. In contrast, net income of rich households falls due to falling factor income. In sum, substituting carbon taxes for labour taxes tends to reduce income inequality in Russia.

## 7.4 Sensitivity Analyses

In general, the results can be quite sensitive to model specifications and parameterisations, such as Armington elasticities, elasticities of transformation, nesting structures, and elasticities of substitution among primary factors, especially the design of the model is important where the policy simulation is implemented. Therefore, the policy simulations are accompanied by series of sensitivity analyses to verify the stability of the results and to recognize the following important determinants:

a) Emission reduction targets (Section 7.4.1).

b) Substitution between intermediates and the value added-energy aggregate (Section 7.4.2).

c) Substitution between labour and the capital-energy aggregate (Section 7.4.3).

d) Labour supply elasticity (Section 7.4.4).

e) Substitution between capital and energy (Section 7.4.5).

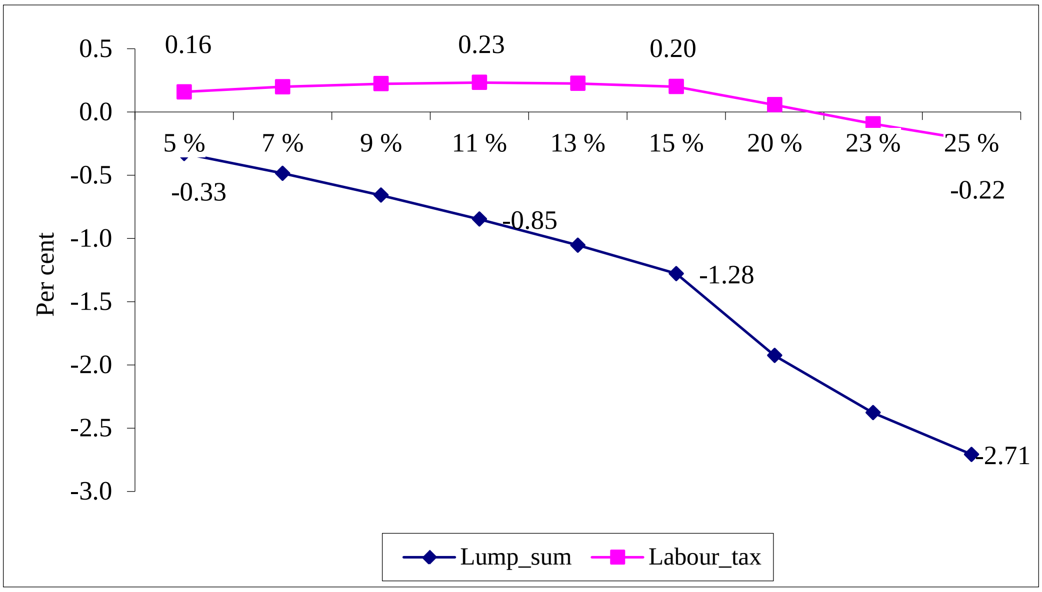
f) Capital mobility/immobility (Section 7.4.6).

g) Substitution among power generation technologies (Section 7.4.7).

### 7.4.1 Emission Reduction Targets

In the central simulation, the magnitude of carbon taxation aims at a targeted reduction of $CO_2$ emissions by 10%. To investigate the welfare effects of carbon taxation under different targets of emission reduction, the target of reduction in $CO_2$ emissions is gradually increased from 5% to 25% under a CT_HS and CT_LT. Figure 7.6 shows the changes in equivalent variation under different reductions in $CO_2$ emissions.

**Figure 7.6: Changes in Equivalent Variation under Different Targets of Reduction in $CO_2$ Emissions (per cent to base household expenditure)**



Source: Model simulation results.

Larger reductions in $CO_2$ emissions are achieved via higher carbon taxes so that increases in energy costs become more pronounced. As a result, the economy is affected more adversely under high targets of emission reduction. For example under a 25% reduction in $CO_2$ emissions, CT_HS leads to welfare losses measured by an EV of 2.71% of base household expenditure, whereas under a CT_LT it is 0.22%. Intuitively, at higher levels of carbon taxation, the bases of carbon taxes become smaller, thereby reducing the magnitude of revenue recycling effect (Parry and Bento, 2000). Under a CT_LT, a strong double dividend is feasible until a 21% reduction in $CO_2$. Overall, macroeconomic and sectoral effects are more pronounced under targets of $CO_2$ emission reduction higher than 10%, i.e., decreases (increases) in total consumption are stronger (less) compared to those under lower reduction targets because of higher increases in energy costs.

### 7.4.2 Substitution between Intermediates and the Value Added-Energy Aggregate

The structure of production nesting in energy and non-energy producing sectors is similar to that implemented in the GTAP energy model. The only difference is that substitution possibilities between intermediates and the value added-energy aggregate are assumed since some substitution possibility is expected in the long run. In the central case simulation, the elasticity of substitution is assumed to equal 0.5. The central case simulation is compared with that where there is no substitution between intermediates and the value added-energy aggregate for all sectors. Under a CT_HS (CT_LT) without substitution possibilities between intermediates and the value added-energy aggregate, introducing carbon taxes leads to smaller (higher) welfare losses (gains) compared to those with substitution possibilities, but the differences in the results are not large. For example, under a CT_HS without substitution possibilities, welfare losses measured by an EV account for 0.72% of base household expenditure, whereas with substitution possibilities it is 0.75%. Under a CT_LT without substitution possibilities, welfare gains are 0.30% of base household expenditure, while with substitution possibilities it is 0.23%. The reason for smaller welfare losses (gains) under a CH_HS (CT_LT) under the assumption of non-substitution possibilities between intermediates and the value added-energy aggregate is as follows. The crude oil and trade product sectors are large domestic consumers of capital. Introducing carbon taxes leads to decreases in capital and labour costs as indicated by decreasing PVAE (Table 7.18). As a result, in the presence of substitution possibilities between intermediates and the value added-energy aggregate, demand for capital is increased in these sectors, diminishing the reduction in the return to capital so that the tax-shifting effect is less pronounced compared to that when there is no substitution between intermediates and the value added-energy aggregate.

### 7.4.3 Substitution between Labour and the Capital-Energy Aggregate

According to the theory, a necessary condition for the occurrence of a strong double dividend is a tax-shifting effect (de Mooij, 2000). The magnitude of the tax-shifting effect between labour and capital depends mainly on elasticities of substitution between these two primary factors. Bovenberg and van der Ploeg (1998) using an analytical general equilibrium model show that high substitutability between labour and the aggregate of resources and the fixed factor increases the possibility for higher employment. Sancho (2010) using a numerical CGE model finds that the elasticity of substitution between capital and labour is the most crucial parameter in determination the effects of environmental taxation.

In the central simulation, elasticities of substitution between labour and the capital-energy aggregate for non-energy producing sectors are taken from the Version 7 of the GTAP database (2007). The elasticities differ by sector with the average value being approximately equal 1.26 (Table 6.4). To investigate the effects of carbon taxation under different values of substitution elasticities between labour and the capital-energy aggregate, the elasticities are increased from 0.5 to 2.0 for non-energy producing sectors. Table 7.25 shows the changes in equivalent variation, labour supply, wages and the return to capital under different elasticities of substitution between labour and the capital-energy aggregate.

**Table 7.25: Changes in EV, Labour Supply and Wages with Different Substitution Elasticities (percentage change)**

| **Elasticity of substitution** | | **0.5** | **1.50** | **2.00** |
|---|---|---|---|---|
| **Equivalent variation** | CT_HS | -0.84 | -0.67 | -0.63 |
| | CT_LT | 0.02 | 0.25 | 0.27 |
| **CT_HS**: | | | | |
| Supply of unskilled labour | | -0.50 | -0.30 | -0.25 |
| Supply of skilled labour | | -0.42 | -0.26 | -0.23 |
| Wage of unskilled labour | | -1.66 | -0.99 | -0.83 |
| Wage of skilled labour | | -1.39 | -0.86 | -0.75 |
| Return to capital | | -2.51 | -2.46 | -2.39 |
| **CT_LT**: | | | | |
| Supply of unskilled labour | | 0.74 | 1.00 | 1.02 |
| Supply of skilled labour | | 0.76 | 0.97 | 0.98 |
| Wage of unskilled labour | | -3.46 | -1.78 | -1.43 |
| Wage of skilled labour | | -3.40 | -1.88 | -1.57 |
| Return to capital | | -1.73 | -2.19 | -2.20 |

Source: Model simulation results.

The sensitivity analysis reveals that elasticities of substitution between labour and the capital-energy aggregate significantly affect the results since these determine the tax-shifting effect. Higher elasticities of substitution result in smaller (higher) welfare losses (gains) under a CT_HS (CH_LT). Moreover, under a CT_HS (CT_LT) with higher elasticities of substitution, decreases (increases) in labour supply are less (more) pronounced. This confirms the conclusion drawn by Bovenberg and van der Ploeg (1998) that high substitutability between labour and the capital-energy aggregate increases the possibility of an employment double dividend. Higher elasticities of substitution between labour and the capital-energy aggregate encourage the tax-shifting effect between capital and labour, improving the efficiency of the tax system. Moreover, high elasticities of substitution between labour and the capital-energy aggregate imply elastic demand for labour. Intuitively, the positive welfare effect resulting from a reduction in labour taxes is larger under more elastic demand for labour since distortions arising from taxation are high in case of elastic demand and supply.

### 7.4.4 Labour Supply Elasticities

In the central simulation, the elasticity of skilled and unskilled labour supply is assumed to equal 0.3. To investigate the stability of the results with respect to different labour supply elasticities, a range of labour supply elasticities from 0.10 to 0.90 is considered. Table 7.26 reveals the changes in equivalent variation as well as labour supply and wages under different labour supply elasticities.

**Table 7.26: Changes in Equivalent Variation, Labour Supply and Wages under Different Labour Supply Elasticities (percentage change)**

| **Labour supply elasticity** | | **0.10** | **0.30** | **0.60** | **0.90** |
|---|---|---|---|---|---|
| **Equivalent variation** | CT_HS | -0.61 | -0.75 | -0.91 | -1.03 |
| | CT_LT | -0.26 | 0.23 | 0.88 | 1.44 |
| **CT_HS**: | | | | | |
| Supply of unskilled labour | | -0.13 | -0.34 | -0.57 | -0.75 |
| Supply of skilled labour | | -0.11 | -0.28 | -0.46 | -0.59 |
| Wage of unskilled labour | | -1.26 | -1.11 | -0.95 | -0.83 |
| Wage of skilled labour | | -1.09 | -0.94 | -0.77 | -0.66 |
| **CT_LT**: | | | | | |
| Supply of unskilled labour | | 0.36 | 1.04 | 1.97 | 2.80 |
| Supply of skilled labour | | 0.37 | 1.02 | 1.86 | 2.56 |
| Wage of unskilled labour | | -1.59 | -2.05 | -2.67 | -3.22 |
| Wage of skilled labour | | -1.53 | -2.12 | -2.86 | -3.47 |

Source: Model simulation results.

Different labour supply elasticities have “qualitatively” different impacts on the results under both revenue recycling policies. For example, under a CT_HS, welfare losses are more pronounced with higher labour supply elasticities. As mentioned, the introduction of carbon taxes compensated by higher lump-sum transfers results in decreases in the supply of unskilled and skilled labour as well as wages. The more elastic labour supply is, the stronger decreases in labour supply and vice versa. The intuitive explanation behind this is that carbon taxes are also implicit taxes on production factors so that the more elastic supply of labour, the larger welfare losses arising from carbon taxation are under a CT_HS.

In contrast, substituting carbon taxes for labour taxes leads to larger welfare gains under an elasticity of labour supply higher than 0.30. This is because higher labour supply elasticities result in larger increases in labour supply as well as larger reductions in wages. As a result, higher increases in labour supply imply higher increases in labour income, whereas lower wages induce lower labour costs for industries. Hence, increases in domestic consumption of some commodities are more pronounced under higher labour supply elasticities. Intuitively, the more elastic supply of labour, the larger welfare gains resulting from a reduction in labour taxes, since taxation of a good or factor which has high elastic demand or/and supply leads to high welfare losses.

Under a perfectly inelastic supply of labour, CT_LT induces the same macroeconomic and sectoral effects as when revenues from carbon taxes would be returned to households in lump-sum form. This is because one single household is recorded in the databases so that lower labour taxes have the same impacts on the consumption patter like higher lump-sum transfers. Labour income taxation given the assumption of perfectly inelastic supply of labour is not distortionary. Furthermore, due to tax incidence, it does not matter whether taxes on labour income or taxes on labour use (social security contributions) are reduced – the macroeconomic and sectoral effects are the same. For example, under a perfectly inelastic supply of labour, substituting carbon taxes for social security contributions results in higher wages, whose increases offset reductions in social security contributions. In other words, a proportional reduction in taxes on labour use is fully absorbed by a proportional increases in gross wages. Hence, the macroeconomic and sectoral effects are the same as when revenues from carbon taxes would be returned to households in lump-sum form.

### 7.4.5 Substitution between Capital and Energy

According the model framework, energy inputs are nested with capital to form a capital-energy aggregate by using a CES function. In the standard model specification, the elasticity of substitution between capital and energy inputs is assumed to equal 0.50 for all non-energy producing sectors, following the GTAP energy model (Burniaux and Truong, 2002). For comparison, the elasticity is increased from 0.50 to 2.5. Table 7.27 shows the changes in equivalent variation and the return to capital under different elasticities of substitution between capital and the energy aggregate.

**Table 7.27: Changes in Equivalent Variation under Different Elasticities of Substitution between Capital and the Energy Aggregate (percentage change)**

| **Elasticity of substitution** | | **0.50** | **1.50** | **2.00** | **2.50** |
|---|---|---|---|---|---|
| **Equivalent variation** | CT_HS | -0.75 | -0.82 | -0.84 | -0.85 |
| | CT_LT | 0.23 | -0.13 | -0.23 | -0.31 |
| **Return to capital** | CT_HS | -2.59 | -1.49 | -1.18 | -0.94 |
| | CT_LT | -2.21 | -1.22 | -0.94 | -0.73 |

Source: Model simulation results.

Under a CT_HS, welfare losses are larger with higher elasticities of substitution between capital and the energy aggregate. Furthermore, substituting carbon taxes for labour taxes under elasticities of substitution higher than 1.00 results also in welfare losses, since the tax-shifting effect between labour and capital is less pronounced. This confirms the conclusion drawn by Bovenberg and van der Ploeg (1998), who state that substitution between the fixed factor and resources should be difficult in order to achieve an increase in employment. Intuitively, the burden on carbon taxes passes less on the factor which is easily substitutable with energy inputs. This is demonstrated with lower decreases in the return to capital under higher elasticities of substitution. In addition, the results are less sensitive to different elasticities of substitution under a CT_HS compared to those under a CT_LT.

### 7.4.6 Capital Mobility

In the standard model specification, capital is assumed to be mobile among sectors, yet internationally immobile. The results are contrasted with those where capital is assumed to be immobile among sectors. Table 7.28 shows the changes in equivalent variation under sectoral mobility and immobility. Given the assumption of sectoral capital immobility, the tax-shifting effect becomes stronger compared to that under the assumption of sectoral capital mobility. As a result, welfare losses are less pronounced in the case where capital is assumed to be sectoral immobile, yet the differences in the results are not large.

**Table 7.28: Changes in Equivalent Variation under Capital Mobility and Immobility (percentage change)**

| | Sectoral | | International | |
|---|---|---|---|---|
| | **Immobile** | **Mobile** | **Immobile** | **Mobile** |
| **CT_HS** | -0.80 | -0.75 | -0.75 | -4.87 |
| **CT_LT** | 0.27 | 0.23 | 0.23 | -4.01 |

Source: Model simulation results.

Furthermore, in the central case, capital is assumed to be international immobile, which implies perfectly inelastic supply of capital. The results are compared with those where capital is assumed to be internationally mobile so that supply of capital is perfectly elastic. As a result, substituting carbon taxes for labour taxes leads to larger welfares losses compared to those where capital is assumed to be international immobile (Table 7.28). The intuition behind this is that under the assumption of international capital mobility, capital can avoid the burden of carbon taxation by flowing abroad so that there is no tax-shifting effect between capital and labour. This result confirms the conclusion drawn by de Mooij and Bovenberg (1998). In the reality, capital is neither perfectly mobile nor perfectly immobile, yet capital is quite mobile especially in the long run (see Obstfeld, 1996).

### 7.4.7 Elasticities of Substitution among Technologies

The electricity sector is greatly impacted from carbon taxes because of its high energy intensity. As a result, electricity intensive sectors such as metals, chemical production, and wood products are adversely affected via a high electricity price. How strong the electricity price would be increased, depends, *inter alia*, on the substitutability among coal-fired, gas-fired, nuclear, and hydro technologies. In our standard model specification, the elasticity of substitution among power generation technologies is assumed to equal 2.00. To investigate the relevance of the technological flexibility within the power generation sector, a range of substitution elasticities among the technologies from 0.50 to 2.5 is considered. Table 7.29 reveals the changes in equivalent variation as well as changes in output and prices under a CT_HS and CT_LT with different elasticities of substitution among the technologies.

**Table 7.29: Changes in Equivalent Variation, Output and Production Costs under Different Elasticities of Substitution among the Technologies (percentage change)**

| **Elasticity of substitution** | | **0.50** | **1.50** | **2.00** | **2.50** |
|---|---|---|---|---|---|
| **Equivalent variation** | CT_HS | -0.79 | -0.76 | -0.75 | -0.74 |
| | CT_LT | 0.29 | 0.25 | 0.23 | 0.21 |
| **Electricity under a CT_HS**: | Output | -6.30 | -5.93 | -5.75 | -5.57 |
| | Costs | 7.59 | 7.09 | 6.85 | 6.62 |
| Coal-fired | Output | -6.84 | -7.50 | -7.83 | -8.15 |
| | Costs | 8.83 | 8.30 | 8.05 | 7.81 |
| Gas-fired | Output | -6.75 | -7.22 | -7.44 | -7.65 |
| | Costs | 8.61 | 8.08 | 7.82 | 7.58 |
| Hydro | Output | -2.39 | 5.50 | 9.27 | 12.90 |
| | Costs | -0.86 | -0.79 | -0.76 | -0.73 |
| Nuclear | Output | -2.39 | 5.50 | 9.27 | 12.90 |
| | Costs | -0.86 | -0.79 | -0.76 | -0.73 |
| **Electricity under a CT_LT**: | Output | -6.10 | -5.71 | -5.53 | -5.35 |
| | Costs | 8.10 | 7.53 | 7.27 | 7.01 |
| Coal-fired | Output | -6.68 | -7.43 | -7.79 | -8.15 |
| | Costs | 9.46 | 8.86 | 8.58 | 8.30 |
| Gas-fired | Output | -6.55 | -7.04 | -7.27 | -7.49 |
| | Costs | 9.16 | 8.56 | 8.27 | 8.00 |
| Hydro | Output | -1.94 | 6.41 | 10.38 | 14.19 |
| | Costs | -0.87 | -0.80 | -0.76 | -0.73 |
| Nuclear | Output | -1.94 | 6.41 | 10.38 | 14.19 |
| | Costs | -0.87 | -0.80 | -0.76 | -0.73 |

Source: Model simulation results.

Under an elasticity of substitution equals 0.50, introducing carbon taxes under both revenue recycling strategies results in reductions in output from all technologies with the decreases from coal- and gas-fired technologies being more pronounced because of higher energy costs. Under higher elasticities of substitution, output from nuclear and hydro technologies increases, whereas reductions in output from coal-technologies become more pronounced. As a result, under higher elasticities of substitution, decreases in the total production of electricity are smaller because of a lower producer price of electricity.

With respect to macroeconomic effects, larger substitutability among the technologies is responsible for smaller welfare losses under a CT_HS because of smaller increases in the consumer price of electricity. In contrast, under a CT_LT, welfare losses are larger under higher elasticities of substitution among the technologies. This is because decreases in production of energy intensive sectors are less when the power generation technologies are more substitutable with each other. Therefore, reductions in demand for capital are less pronounced, which leads to smaller decreases in capital costs compared to those under higher elasticities of substitution. As a result, the tax-shifting effect between labour and capital is weaker given the assumption of high elasticities of substitution between power generation technologies.

## 7.5 Substituting Carbon Taxes for Labour Taxes under a Cournot Oligopoly

### 7.5.1 Macroeconomic and Fiscal Effects

The existence of a Cournot oligopoly in the markets for natural gas, minerals, petroleum products, chemical production, and metals, increases the cost of carbon taxation in Russia. Under a Cournot oligopoly, substituting carbon taxes for labour taxes results in welfare losses with welfare losses being more pronounced in case of Cournot oligopoly with free entry and exit compared to those when blocked entry and exit is assumed (Column 2 and 3 of Table 7.30). Moreover, increases in household income are less pronounced given the assumption of a Cournot oligopoly. In contrast, the environmental tax reform leads to welfare gains as well as higher household income under perfect competition in output market.

**Table 7.30: Macroeconomic and Aggregated Effects Compared to Model Base**

| | (1)<br>Perfect competition | (2)<br>Cournot oligopoly [a] | (3)<br>Cournot oligopoly [b] |
|---|---:|---:|---:|
| Equivalent variation (million USD) | 667.79 | -450.08 | -865.56 |
| Exchange rate (per cent) | 0.11 | -0.01 | 0.23 |
| Tax rates on labour income (per cent) | -15.97 | -15.83 | -15.12 |
| **Household income** (million USD)**:** | 1375 | 320 | 188 |
| Capital income | -4,401 | -4,275 | -4,731 |
| Unskilled labour income | 4,270 | 4,148 | 3,688 |
| Skilled labour income | 1,954 | 1,903 | 1,735 |
| Land income | 40 | 15 | 16 |
| Natural resource income | -489 | -701 | -519 |
| **Factor prices** (per cent): | | | |
| Capital | -2.21 | -2.15 | -2.25 |
| Unskilled labour | -2.05 | -2.06 | -2.07 |
| Skilled labour | -2.12 | -2.14 | -2.14 |
| Natural resource | -5.98 | -6.19 | -8.66 |
| **Factor supply** (per cent): | | | |
| Unskilled labour | 1.04 | 1.03 | 0.95 |
| Skilled labour | 1.02 | 1.00 | 0.93 |
| Land | 0.62 | 0.23 | 0.25 |
| **Government revenues** (million USD): | -867 | -1100 | -1122 |
| Export taxes | 502 | 433 | 538 |
| Import taxes | -4 | -28 | -31 |
| Carbon taxes | 8,373 | 8,248 | 7,985 |
| Consumption taxes | -1,050 | -1,087 | -1,169 |
| Taxes on unskilled labour income | -5,570 | -5,547 | -5,380 |
| Taxes on skilled labour income | -2,612 | -2,599 | -2,508 |
| Social security contrib. from unskilled labour | -33 | -36 | -43 |
| Social security contrib. from skilled labour | -17 | -18 | -20 |
| Capital taxes | -418 | -408 | -451 |
| Mineral resource extraction taxes | -41 | -59 | -44 |
| Land taxes | 3 | 1 | 1 |
| **Government expenditures** (million USD): | 285 | 64 | 37 |
| Lump-sum transfers | 284 | 66 | 39 |
| Production subsidies | 1 | -2 | -2 |

[a] Cournot oligopoly with blocked entry and exit.

[b] Cournot oligopoly with free entry and exit.

Source: Model simulation results.

The reasons for welfare losses from carbon taxation in the presence of imperfect competition are as follows. First, substituting carbon taxes for labour taxes induces reductions in domestic demand in imperfectly competitive energy and energy intensive markets because of higher consumer prices. Since domestic supply is already sub-optimal under a Cournot oligopoly, further decreases lead to higher consumer welfare deadweight losses. Second, introducing carbon taxes results in losses in economies of scale.

Under a Cournot oligopoly with blocked entry and exit, final consumers are affected by changes in mark-ups via changes in perceived elasticities of demand as well as the occurrence of economic profit (loss). Under a Cournot oligopoly with free entry and exit, an economic profit (loss) leads to entry (exit) of firms so that changes in mark-ups are determined not only by changes in perceived elasticities of demand, but also by changes in the number of firms. Sectoral effects of carbon taxes are explained in more detail below in Chapter 7.5.2.

## 7.5.2 Sectoral Effects

### 7.5.2.1 Energy Commodities

Domestically produced natural gas is assumed to be sold at the average cost price[38] in the domestic market, whereas the socially desirable price would equal marginal cost. Introducing carbon taxes raises the consumer price of natural gas, thereby exacerbating pre-existing distortions arising from the inefficient price policy. Moreover, a reduction in the total production of natural gas results in losses in economies of scale so that firms operate at a lower scale level (Columns 6 of Tables 7.31 and 7.32). Overall, the producer price of natural gas declines because of lower production costs, yet losses in economies of scale diminish the reduction in the producer price, to certain extent, via higher average fixed costs.

Carbon taxes are not levied on exports of energy so that Russian natural gas becomes more competitive in the export market because of a decrease in production costs. As a result, domestic producers of natural gas face less elastic export demand via an increase in their market share. Columns 4 of Tables 7.31 and 7.32 show a reduction in the perceived elasticity of demand for natural gas which reflect changes in the competitiveness of Russian gas in the export market.

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[38] The assumption of average cost pricing in the domestic market is based on the fact that domestic prices of natural gas in Russia are administratively regulated. Under an average cost pricing, producers of natural gas operate at zero profit.

**Table 7.31: Sectoral Effects of Carbon Taxation under a Cournot Oligopoly with Blocked Entry and Exit (percentage changes except for profit: million USD)**

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | Domestic demand | | Mark-up | Elasticity of demand | Profit (mill. USD) | Economies of scale |
| | PC[a] | IC[b] | | | | |
| Natural gas | -6.64 | -6.65 | 1.47 | -1.45 | -6.97 | -2.36 |
| Petroleum products | -2.62 | -2.88 | 0.00001 | -0.00001 | 10.49 | -2.35 |
| Chemical products | -3.42 | -3.07 | -0.16 | 0.16 | -308.70 | -4.80 |
| Metals | -2.64 | -2.17 | -0.11 | 0.11 | -498.33 | -3.74 |
| Minerals | -2.86 | -2.30 | 0.07 | -0.07 | 32.81 | -1.33 |

[a] Perfect competition.
[b] Cournot oligopoly with blocked entry and exit.
Source: Model simulation results.

**Table 7.32: Sectoral Effects of Carbon Taxation under a Cournot Oligopoly with Free Entry and Exit (percentage changes)**

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | Domestic demand | | Mark-up | Elasticity of demand | Number of firms | Economies of scale |
| | PC[a] | IC[b] | | | | |
| Natural gas | -6.64 | -6.74 | 1.90 | -1.53 | -0.34 | -1.91 |
| Petroleum products | -2.62 | -3.10 | -0.23 | -0.00001 | 0.23 | -2.67 |
| Chemical products | -3.42 | -4.15 | 4.65 | 0.22 | -4.65 | -1.83 |
| Metals | -2.64 | -3.00 | 3.99 | 0.15 | -3.97 | -1.20 |
| Minerals | -2.86 | -3.32 | -1.47 | -0.10 | 1.60 | -3.45 |

[a] Perfect competition.
[b] Cournot oligopoly with free entry and exit.
Source: Model simulation results.

In the model, this effect operates through equations 7.1 and 7.2:

$$DEL\exp_c = elastw_c - SH\exp_c * (elastw_c - 1), \tag{7.1}$$

$$SH\exp_c = \frac{QE_c * PWE_c}{QET_c * PET_c}, \tag{7.2}$$

where $DEL\exp_c$ is the perceived elasticity of export demand, $elastw_c$ is the elasticity of substitution between Russian gas and gas from the rest of the world (ROW), $SH\exp_c$ is the value share of Russian gas exports in global gas exports, $QE_c$ is export supply of gas from Russia, $PWE_c$ is the export price of Russian gas, $QET_c$ is the global gas export and $PET_c$ is the composite price of global gas exports. Equation 7.1 shows that the higher the market share, the lower is the perceived elasticity of export demand.

According to the first-order condition for profit maximization under a Cournot oligopoly with blocked entry and exit (equation 7.3), a reduction in the perceived elasticity of demand ($DEL_c$) increases the mark-up ($MK_c$) (Column 3 of Table 7.31), implying more market power of Russian gas producers in the export market.

$$MK_c = \frac{\Omega}{N_a * DEL_c}. \tag{7.3}$$

Furthermore, introducing carbon taxes leads to the occurrence of economic losses in the natural gas sector (Column 5 of Table 7.31). Generally, the occurrence of economic profit (losses) is determined by different factors, such as economies of scale, initial elasticities of export and domestic demand, changes in elasticities of export and domestic demand, and changes in production costs. For instance, losses in economies of scale tend to generate economic losses via increasing average fixed costs. While export supply of natural gas is increased and there is a reduction the perceived elasticity of demand, domestic producers of natural gas experience economic losses, driven by a strong reduction in domestic demand as well as losses in economies of scale. The economic loss establishes an incentive for firms to leave the sector. Given the assumption of a Cournot oligopoly with free entry and exit, the increase in the mark-up on gas exports is larger compared to that with blocked entry and exit because of a smaller number of firms (cf. Column 3 of Table 7.31 and 7.32).

Introducing carbon taxes leads to a decline in the domestic demand for petroleum products because of higher consumer prices. This exacerbates pre-existing distortions arising from imperfect competition. Because of lower production costs, domestic producers of petroleum products become more competitive compared to foreign firms. Column 4 of Tables 7.31 and 7.32 shows a small reduction in the perceived elasticity of demand, which results from a higher market share of domestically produced petroleum products in the domestic market. Under a Cournot oligopoly with blocked entry and exit, less elastic domestic demand for petroleum products induces a small increase in the mark-up on domestically sold petroleum products (Column 3 of Table 7.31). While there are losses in economies of scale, substituting carbon taxes for labour taxes leads to an economic profit (Column 5 of Table 7.31). In comparison to natural gas, the reduction in domestic demand petroleum products is less pronounced. Moreover, there is an increase in the export price of petroleum products and a small reduction in the perceived elasticity of demand. In the presence of an economic profit, firms are expected to entry the market (Column 5 of Table 7.32). Hence, under the assumption of free exit, domestic consumers of petroleum products experience a reduction the mark-up (Column 3 of Table 7.32). As a result, the decline the mark-up on domestically sold petroleum products alleviates partially the consumer deadweight loss arising from imperfect competition.

#### 7.5.2.2 Energy Intensive Commodities

Declining domestic demand for chemical products and metals resulting from higher producer prices exacerbates consumer deadweight losses arising from imperfect competition. Furthermore, introducing carbon taxes exacerbates the pre-existing distortions via higher mark-ups under a Cournot oligopoly with free entry and exit. Due to increases in production costs, domestic producers of chemical products and metals become less competitive compared to foreign rivals so that there are decreases in the export and domestic demand for chemical products and metals. As a result, domestic demand becomes more elastic via lower market shares. Columns 4 of Tables 7.31 and 7.32 show increases in the perceived elasticities of demand for chemical products and metals. On the one hand, increasing perceived elasticities of demand reduce the mark-ups under a Cournot oligopoly with blocked entry and exit, thereby improving consumer welfare to certain extent. On the other hand, there are economic losses (Column 5 of Table 7.31) because of strong reductions in domestic and export demand for chemical products and metals and losses in economies of scale as well as increasing perceived elasticities of domestic demand. In the presence of economic losses, the equilibrium is not stable since some firms want to leave the unprofitable markets. Given the assumption of free entry and exit, the economic losses pass on to final consumers in terms of increasing mark-ups (Column 3 of Table 7.31), driven by less competition in the domestic chemical products and metals markets. As a result, as shown in Column 2 of Table 7.31, decreases in domestic demand for chemical products and metals under a Cournot oligopoly with free entry and exit are more pronounced compared to those under perfect competition.

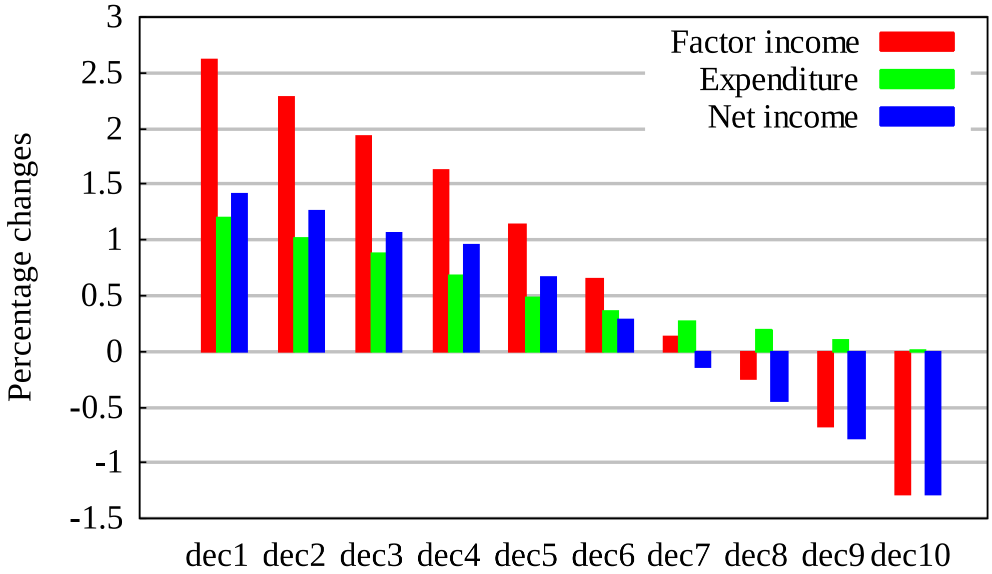
#### 7.5.2.3 Non-Energy Intensive Commodities

Substituting carbon taxes for labour taxes alleviates consumer deadweight losses arising from imperfect competition in the mineral market since there is a reduction in the producer price of minerals resulting from lower production costs. As a result of lower production costs as well as a depreciation of the currency, domestic producers of minerals become more competitive in the domestic market compared to foreign rivals. Therefore, the perceived elasticity of demand falls due to a higher market share of domestically produced minerals in the domestic market. Under a Cournot oligopoly with blocked entry and exit, the declining perceived elasticity of demand for minerals results in a higher mark-up (Column 3 of Table 7.31). Moreover, there are losses in economies of scale resulting from a decline in the total production of minerals due to lower domestic demand. Since the energy intensive metal sector is the largest domestic consumer of minerals, a decreasing demand for metals induces lower domestic demand for minerals. Exports of minerals, however, increase due to declining production costs. Despite losses in economies of scale resulting in higher average fixed costs, introducing carbon taxes leads to an economic profit (Column 5 of Table 7.31) in the mineral sector because of a decrease in production costs and an increasing export price as well as a declining perceived elasticity of demand. The economic profit attracts new firms to entry the market, which reduces the mark-up on domestically sold minerals, given the assumption of free entry and exit (Column 3 of Table 7.32). The reduction in the mark-up, furthermore, alleviates consumer deadweight losses arising from imperfect competition.

### 7.5.3 Carbon Taxation and Income Inequity

Carbon taxes under a Cournot oligopoly have qualitatively similar implications on the income distribution as discussed in Section 7.3.4. Figure 7.7 shows the changes in total factor income, consumption expenditures and net income by decile.

**Figure 7.7: Changes in Total Factor Income, Total Consumption Expenditures and Net Income[a] by Decile (per cent)**



**dec1** represents the poorest ten per cent of the population, **dec10** the richest ten per cent.
[a] Net income is the aggregated effect of expenditure and factor income changes.
Source: Model simulation results.

Introducing carbon taxes induces a quite regressive impact on the income distribution, yet the environmental tax reform is still progressive. The main difference in the results between substituting carbon taxes for labour taxes under perfect competition and a Cournot oligopoly is that increases in net income are less pronounced in the presence of a Cournot oligopoly.

### 7.5.4 Sensitivity Analyses

**Cost disadvantage ratio.** According to our results, the cost of the environmental tax reform in the presence of a Cournot oligopoly in commodity markets is higher compared to that under perfect competition. How strong this effect would be, depends on the magnitude of pre-existing distortions. In the central case, a mark-up of 15% is assumed for all imperfectly competitive markets. Under lower mark-ups, the economy is less adversely affected by carbon taxes and vice versa. For example, under a mark-up of 5%, substituting carbon taxes for labour taxes results in welfare gains as measured by an EV of 0.11% of base household expenditure, whereas under a mark-up of 15% those are welfare losses: 0.30%. Given the assumption of free entry and exit, the mark-up is related to a cost disadvantage ratio (CDR), which defines the share of fixed costs in total production costs (Francoise, 1998; Harrison et al., 1994). Losses in economies of scale pass on to consumers in terms of a higher mark-up. Losses in economies of scale can significantly increase the cost of the environmental tax reform. This confirms the conclusion drawn by Böhringer et al. (2008), who analysed the structural change induced by environmental taxation for Germany under an imperfectly competitive market structure.

# 8 Conclusions

## 8.1 Summary of Simulation Results and Discussion

Based on simulation results, the main conclusions are summarized as follows. Introducing carbon taxes compensated by an increase in lump-sum transfers leads to welfare losses measured by an equivalent variation of 0.75% of base household expenditure. The economy is adversely affected by carbon taxes via increased energy costs so that there are reductions in domestic consumption as well as production in almost all sectors. In comparison, substituting carbon taxes for labour taxes is a more desirable revenue recycling policy since this leads even to welfare gains measured by equivalent variation of 0.23% of base household expenditure. In other words, there is a strong double divided in terms of welfare when revenues from carbon taxes are refunded through a reduction in labour taxes. Other macroeconomic and sectoral effects resulting from substituting carbon taxes for labour taxes are summarized as follows:

1) There are increases in the supply of unskilled and skilled labour by 1.04% and 1.02%, respectively. This indicates the occurrence of an employment double dividend (Bovenberg and van der Ploeg, 1998). High labour supply leads to reductions in wages, implying lower labour costs for industries. Moreover, supply of land is increased by 0.62% associated with higher production of agricultural products.

2) Returns to capital and natural resources are reduced because of lower demand for these factors so that the burden of carbon taxes is not fully passed on to final consumers, yet is partially absorbed by lower factor prices. This indicates the tax-shifting effect between labour, capital and natural resources (de Mooij and Bovenberg, 1998; Bovenberg and van der Ploeg, 1998; Bento and Jacobsen, 2007).

3) Substituting carbon taxes for labour taxes results in higher revenues from export taxes because of both a depreciation of the currency and higher export supplies of energy commodities as well as non-energy intensive commodities. In particular, the increase in revenues from export taxes on crude oil, natural gas, and petroleum products is strongly pronounced. Export taxes lower the domestic price level of energy so that there is oversupply of energy in the domestic market. Therefore, introducing carbon taxes has also a corrective effect since this leads to an increase in export supply and a reduction in domestic demand for energy. Increases in export supply of energy are

associated with higher revenues from export taxes, which reduce the cost of the environmental tax reform. Moreover, there is an increase in the revenue from land taxes. Intuitively, high revenues from other taxes allow a larger reduction in labour taxes, furthermore alleviating the tax distortion in the labour market.

4) In contrast, substituting carbon taxes for labour taxes leads to reductions in the revenues from labour taxes because of both lower tax rates and wages. Revenues from capital taxes and mineral resource extraction taxes are also reduced due to lower returns to these factors. Furthermore, revenues from consumption taxes decrease due to a lower value of total consumption.

5) Total domestic production of energy commodities is reduced, driven by lower domestic demand. Nevertheless, domestic producers of energy become more competitive in domestic and export markets because of lower production costs and a depreciation of the currency. As a result, there are increases in the export supply of crude oil, coal, petroleum products, and natural gas.

6) Energy intensive commodities such as electricity, wood products, chemical products, and metals are affected most adversely by the introduction of carbon taxes. Due to high energy costs, domestic producers of energy intensive commodities become less competitive compared to foreign firms. As a result, there are increases in import demand for some energy intensive commodities, whereas export and domestic demand for all domestically produced energy intensive commodities is reduced.

7) In contrast, domestic producers of non-energy intensive commodities such as textiles, agriculture, and food products become more competitive in domestic and export markets compared to foreign rivals. As a result, substituting carbon taxes for labour taxes leads to increases in export supplies of all non-energy intensive commodities. Moreover, domestic demand for most domestically produced non-energy intensive commodities is also increased because of increased household income, while import demand for non-energy intensive commodities is reduced via a substitution effect.

8) Carbon taxes have a strong regressive impact on income distribution since the expenditure shares on coal, gas and electricity are especially high by poor households compared to those by rich households, while the expenditure share on petroleum products is larger by rich households. Despite a regressive impact of carbon taxes, the

> environmental tax reform tends to be quite progressive if revenues from carbon taxes are refunded via a reduction in labour taxes or as lump-sum transfers in favour of poor household groups. Hence, substituting carbon taxes for labour taxes cannot only improve national welfare, but reduce also income inequality in Russia. Furthermore, a lower labour tax rate may alleviate income tax evasion, which is a prominent problem in Russia and has been shown to strongly correlate with the tax rate level (Gorodnichenko et al., 2009).

To examine the stability of the results under different model parameterizations, several sensitivity analyses were carried out. The sensitivity analyses indicate that the macroeconomic and sectoral effects of carbon taxes strongly depend on i) the labour supply elasticity, ii) elasticities of substitution between labour and the capital-energy aggregate, iii) elasticities of substitution between capital and energy, and iv) international capital mobility. For instance, substituting carbon taxes for labour taxes results in higher welfare gains under a high labour supply elasticity as well as high elasticities of substitution between labour and the capital-energy aggregate and low elasticities of substitution between capital and energy. Intuitively, the more elastic demand and supply of labour, the larger welfare losses arising from labour taxation. Therefore, substituting carbon taxes for labour taxes tends to be a more preferable revenue recycling strategy under elastic demand and supply of labour. Another crucial aspect is the tax-shifting effect between labour and capital. Under the assumption of international capital immobility, capital bears some burden of carbon taxation. The higher elasticities of substitution between labour and the capital-energy aggregate as well as the lower elasticities of substitution between capital and energy, the more pronounced the tax-shifting effect. The magnitude of the tax-shifting effect between capital and labour is indicated by reductions in the return to capital. In contrast, given the assumption of perfect capital mobility across borders, introducing carbon taxes under both revenue recycling schemes – an increase in lump-sum transfers to households and a reduction in tax rates on labour income – leads to substantial welfare losses compared to those in the central case simulation. Nevertheless, in reality capital is neither perfectly mobile nor perfectly immobile (Obstfeld, 1996) so that some tax-shifting effect between capital and labour is expected to occur, yet this effect will be rather moderate in the long run.

In the central policy simulation, substituting carbon taxes for labour taxes improves national welfare. Nevertheless, non-tax distortions such as imperfect competition should not be neglected. In the presence of a Cournot oligopoly in the market for natural gas, petroleum products, chemical products, metals, and minerals, the cost of carbon taxation in terms of welfare is higher compared to perfect competition being assumed. The reason for this is that carbon taxes exacerbate pre-existing distortions arising from imperfect competition and leads to losses in economies of scale. As a result, substituting carbon taxes for labour taxes under a Cournot oligopoly in output markets can lead to welfare losses.

An occurrence (failure) of a strong double dividend is not the primary reason why an environmental tax reform should (not) be carried out. The purpose of environmental taxes is to internalize negative environmental externalities. Introducing carbon taxes in Russia aims at a reduction in $CO_2$ emissions to combat climate change. The results show that an environmental tax reform can lead to non-environmental welfare gains under perfect competitive markets structure. Furthermore, Russia could benefit from selling non-utilized emission permits in international carbon markets. Such carbon sales have been reported for several Central European countries at prices from 6-12 USD/ton of $CO_2$, but not yet for Russia (Aldrich and Koerner, 2012). The 10% emission reduction simulated for Russia in this analysis would be equivalent to 158.61 million metric tons of $CO_2$ equivalents. At a price of about 12 USD/ton of $CO_2$, this would more than compensate for the welfare losses simulated under imperfect competition. Most market observers expect that there will be a global carbon reference price by 2020 and expect this price to be around 35 USD/ton of $CO_2$ (Point Carbon, 2011). Under such a price scenario, the benefits from carbon sales would exceed our simulated welfare losses under imperfect competition by a factor 6-12, depending on the assumption made on entry and exit of firms. It should be noted that Russia may have some market power in the global carbon trading market. Hence, an intergovernmental emission trading may be more rational from Russian perspective compared to trading among firms according to the Joint Implementation mechanism (Böhringer and Löschel, 2004; Böhringer et al., 2007).

A carbon tax can be considered as an indirect tax on other emissions stemming from usage of energy inputs so that introducing carbon taxes will also lead to reductions in non-$CO_2$ GHGs such as $CH_4$, $N_2O$, and F-gases as well as local air pollution such as sulphur dioxide ($SO_2$), nitrogen oxides ($NO_x$) and carbon monoxide (CO). At present, there are emission payments in Russia, yet these are substantially lower compared to those levied in developed countries.

Improvement in energy efficiency associated with the introduction of carbon taxes is another important aspect. Energy efficiency may improve due to the optimization of existing plants, the substitution of lower emission energy sources for higher emission sources and the adoption of 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 innovation in energy-saving technologies. In the presence of large technical potential for energy efficiency improvement, the marginal cost of energy efficiency improvement in Russia is lower compared to many developed countries which are quite close to their production possibility frontier. Hence, the welfare gains resulting from the simulated introduction of carbon taxes in Russia may be higher if positive dynamic welfare effects are captured. In addition, increasing environmental taxes on usage energy tends to encourage a sustainable use of energy resources.

Furthermore, the cost of the introduction of carbon taxes under a Cournot oligopoly may be overestimated. An oligopoly with homogenous products and symmetric firms is assumed in this analysis, while product heterogeneity and asymmetry of firms with respect to production costs and emission intensity may be more realistic for some sectors. Introducing carbon taxes can shift production from less efficient to more efficient firms (Simpson, 1995), which may reduce the negative welfare effects found.

An important lesson emerging from this analysis is that the current energy policy can, *inter alia*, determine the design of an environmental tax policy. For example, domestic prices of electricity and gas are administratively regulated in Russia and there are high export taxes on natural gas, crude oil and petroleum products. Hence, taxation of energy inputs according to their carbon intensity is not necessarily the most cost effective policy to achieve certain emission abatement so that a differentiation of carbon tax rates among energy inputs can come into consideration. In other words, the introduction of carbon taxes can also correct the inefficiencies of the current energy policy. Probably, the superior policy would be to directly correct inefficiencies arising from government intervention. For example, high export taxes on energy in Russia can be justified on grounds of economic efficiency and income equity since Russia may have some market power in world energy markets and energy resources are mainly owned by rich households. Nevertheless, concerns are that export taxes on energy are “too high”, especially on crude oil and petroleum products, which may lead to welfare losses. Administrative price regulation of natural gas and electricity is desirable for poor households and this can prevent domestic producers from exercising their market power in domestic markets. Nevertheless, administrative price regulation is not the optimal policy to deal with these issues.

Regarding the sectoral effects of carbon taxation, it is found that domestic producers of energy intensive commodities would lose market shares in domestic and export markets in case of carbon taxation. Apart from a regressive distributional effect of carbon taxation, the concern to lose competitiveness in some energy intensive sectors can be another important source of political opposition (Fullerton et al., 2008). A tax exemption of such sectors is therefore often discussed and sometimes implemented (OECD, 1995 and 2006). Nevertheless, exemptions due to competitiveness concerns are hard to justify on both economic and environmental grounds (Böhringer and Rutherford, 1997; Ekins and Speck, 1999). The intuitive explanation behind this is that tax exemptions imply narrowing tax bases, thereby resulting in higher welfare costs of an abatement tax policy. When looking at the effects of carbon taxes in Russia, one should not neglect that domestically produced energy commodities as well as labour intensive commodities become more competitive compared to foreign rivals. For the economy as a whole, what matters is the overall welfare effect which is found to be positive for Russia under perfect competition as well as a Cournot oligopoly in some output markets, if the opportunity for carbon trading is given. In addition, changes in competitiveness are moderate according to our simulation results, depending mainly on the magnitude of carbon taxation. The magnitude of changes mainly depends on emission reduction targets as well as revenue refunding schemes.

## 8.2 Model Limitations and Further Research

There are some limitations to this analysis related to the model features. Such model limitations as well as the policy simulation results of policy simulations provide scope for further research. A comparative static single country CGE model is used. Hence, technological change, which would result from investment in energy efficiency, is not captured in this analysis. Introducing carbon taxes is expected to accelerate the diffusion of new energy-efficient and less carbon-intensive technologies and encourage innovation processes in the long-run. For example, Goulder and Schneider (1999) assert that the existence of price-induced technological change can result in lower costs of environmental policy. A dynamic CGE model with endogenous technological change is obvious an appropriate tool to account for dynamic welfare effects resulting from an environmental tax reform.

The analysis is based on the assumption of perfectly elastic demand and supply of the ROW. A multi-country CGE model can be employed to provide more realistic model design with respect to trade flows between Russia and the ROW. In particular, this is important for addressing the carbon leakage issue, a prominent problem of abatement policies (Babiker, 2005). Hence, a potential research question could be an estimation of carbon leakage resulting from the introduction taxes in Russia. On one hand, Russia exports its energy resources mainly to less energy- and carbon-intensive economies so that introducing carbon taxes will shift the supply of energy towards more energy efficient countries. On the other hand, Russia is one of the largest exporters of energy so that an increase in export supply of energy can lower the world price level. As a result, demand for energy in other countries – more energy intensive than Russia – could also increase. Without a quantitative estimation it is difficult to draw any conclusion about the magnitude of the carbon leakage rate. A multi-country CGE model would be required to address the issue of carbon leakage explicitly. In particular, the measure of carbon leakage becomes of high relevance, if different revenue recycling policies are compared.

The results show that welfare costs of the introduction of carbon taxes in Russia become higher if a Cournot oligopoly for output markets is assumed so that welfare costs arising from imperfect competition should not be neglected. This raises the issue of alternative revenue recycling policies. The analysis could be extended by a comparison of other revenue recycling strategies. For example, in the presence of imperfect competition, carbon leakage and losses in competitiveness, an output-based refunding could be considered. Under such an output-based refunding, revenues from carbon taxes are recycled through output subsidies to imperfectly competitive sectors (Sterner and Höglund, 2000; Fischer, 2011; Fischer and Fox, 2009). Output-based refunding instead of a reduction in labour taxes could, however, diminish the inequity reducing effect of the policy package. Therefore, some combination of these two revenue allocation schemes could be considered. Furthermore, the analysis can be further extended by comparison of other possible revenue refunding policies, such as reductions in capital taxes or reductions in consumption taxes, or some combination of them can also come into consideration. For example, Jorgenson and Wilcoxen (1993) by employing a dynamic general equilibrium model find that substituting carbon taxes for capital taxes can lead to an increase in GNP. It is also important to recognize that such revenue recycling schemes could raise trade-off between income equity and economic efficiency. For example, given the assumption of international capital mobility, a reduction in capital taxes is likely more rational on grounds of economic efficiency compared to a reduction in labour taxes, yet this can exacerbate income inequality in Russia.

Another important limitation is the empirical foundation of the analysis. The analysis is based on Version 7 of GTAP database, which represents the global economy in 2004. Recently, some structural changes as well as changes in the Russian tax system took place. Hence, using an updated database would increase the credibility of the simulation results. Furthermore, parameterization of the model is a key determinant of the results. To our best knowledge, there are no estimations on the most crucial parameters, such as the labour supply elasticity as well as elasticities of substitution between labour, capital and energy for Russia. Almost all elasticities used the model are mainly taken from the GTAP database. Hence, the analysis could benefit from the estimation of such parameters to provide more confidence in the results. The results of policy simulations suggest that the most important parameters for an econometrical estimation are i) labour supply elasticities, ii) elasticities of substitution between capital and labour, iii) elasticities of substitution between energy, labour and capital. The analysis could also benefit from the investigation of international capital mobility since this determines, *inter alia*, the tax-shifting effect between capital and labour. Another relevant aspect associated with parameterization is the nesting structure. The nesting structure used in the model is similar with that implemented in the GTAP energy model, but this slightly differs between energy producing, non-energy producing sectors and the electricity sector. One of the main features of the nesting structure used for non-energy producing sectors is that labour is substitutable with the capital-energy aggregate. Such a nesting specification is used in the GTAP energy model (Burniaux and Truong, 2002) as well as the GREEN model (Burniaux et al., 1992). An alternative nesting structure could be a value added-energy aggregate with the energy aggregate being substitutable with the capital-labour aggregate (e.g. Paltsev et al., 1995; Manne et al., 1995). Empirical studies are controversial with respect to which nesting structure would be more appropriate. This may differ by economy and by sector.

The analysis is focused on $CO_2$ emissions, whereas the effects of the introduction of carbon taxes on non $CO_2$ GHGs are not captured. At the same time, $CH_4$, $N_2O$ and F-gases are large sources of GHGs emissions: for example, approximately 21.7% of total GHGs in Russia come from $CH_4$. In addition, according to estimates by Reilly et al. (2004), a reduction in non $CO_2$ GHGs can be often achieved at relatively low costs. Hence, taxation of non $CO_2$ GHGs can also come into consideration. According to OECD (2001), non $CO_2$ GHGs which may be suitable for taxation are i) $CH_4$ from landfills, ii) $CH_4$ emissions from natural gas and oil production, and iii) $N_2O$ from use of fertilizers. On one hand, the theoretical literature on optimal taxation suggests that a targeted taxation typically is a more efficient policy instrument to correct externalities compared to some “proxy” taxes. This is because targeted instruments provide the “right” behaviour incentives, especially this becomes relevant if there many substitution possibilities such as substitution among energy inputs. On the other hand, a more complicated tax system is associated with high compliance costs resulting from taxation (Alm, 1996). An evaluation of the design of environmental taxation in the presence of multi-externalities is also a potential field for further research.

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# Appendixes

## Appendix A: Derivation of Equation (4.4.12)

The tax-interaction effect ($\partial W^{I}$) is defined as the following:

$$\partial W^{I} = (1+M)\tau_{L}\frac{\partial H}{\partial \tau_{C2}}, \tag{a1}$$

where $M = \dfrac{\tau_{L}\dfrac{\partial H}{\partial \tau_{L}}}{T-H-\tau_{L}\dfrac{\partial H}{\partial \tau_{L}}}$. (a2)

Substituting (a2) into (a1), we obtain:

$$\partial W^{I} = \left(\frac{T-H}{T-H-\tau_{L}\dfrac{\partial H}{\partial \tau_{L}}}\right)\tau_{L}\frac{\partial H}{\partial \tau_{C2}}. \tag{a3}$$

Multiplying by $\dfrac{\dfrac{\partial H}{\partial \tau_{L}}}{\dfrac{\partial H}{\partial \tau_{L}}}$ yields:

$$\partial W^{I} = \frac{M(T-H)\dfrac{\partial H}{\partial \tau_{C2}}}{\dfrac{\partial H}{\partial \tau_{L}}}, \tag{a4}$$

Making use of the Slutsky equation: $\dfrac{\partial H}{\partial \tau_{C2}} = \dfrac{\partial H^{C}}{\partial \tau_{C2}} - C_{2}\dfrac{\partial H}{\partial I}$ and the Slutsky symmetry property: $\dfrac{\partial H^{C}}{\partial \tau_{C2}} = -\dfrac{\partial C_{2}{}^{C}}{\partial \tau_{L}}$, the term $\dfrac{\partial H}{\partial \tau_{C2}}$ in the numerator of (a4) can be defined as the following:

$$\frac{\partial H}{\partial \tau_{C2}} = -\frac{\partial C_{2}{}^{C}}{\partial \tau_{L}} - C_{2}\frac{\partial H}{\partial I}, \tag{a5}$$

where $c$ states for compensated and $I$ is the disposable household income.

Making use of the Slutsky equation, the term $\dfrac{\partial H}{\partial \tau_{L}}$ can be defined as the following:

$$\frac{\partial H}{\partial \tau_L} = \frac{\partial H^C}{\partial \tau_L} - (T-H)\frac{\partial H}{\partial I}. \tag{a6}$$

Differentiating the time endowment constraint (4.4.8) with respect to $\tau_L$, we obtain:

$$\frac{\partial H^C}{\partial \tau_L} = -\frac{\partial Q_1{}^C}{\partial \tau_L} - \frac{\partial Q_2{}^C}{\partial \tau_L}. \tag{a7}$$

Substituting (a7) into (a6) gives:

$$\frac{\partial H}{\partial \tau_L} = -\frac{\partial Q_1{}^C}{\partial \tau_L} - \frac{\partial Q_2{}^C}{\partial \tau_L} - (T-H)\frac{\partial H}{\partial I}. \tag{a8}$$

Differentiating (4.4.2) and (4.4.3) with respect to $\tau_L$, we obtain:

$$\frac{\partial Q_1{}^C}{\partial \tau_L} = \frac{\partial C_1{}^C}{\partial \tau_L} - \frac{\partial M^C}{\partial \tau_L}, \tag{a9}$$

$$\frac{\partial Q_2{}^C}{\partial \tau_L} = \frac{\partial C_2{}^C}{\partial \tau_L} + \frac{\partial X^C}{\partial \tau_L}. \tag{a10}$$

Substituting (a9) and (a10) into (a8), we obtain:

$$\frac{\partial H}{\partial \tau_L} = -\frac{\partial C_1{}^C}{\partial \tau_L} - \frac{\partial C_2{}^C}{\partial \tau_L} - (T-H)\frac{\partial H}{\partial I}. \tag{a11}$$

Substituting (a5) and (a11) into (a4) gives:

$$\partial W^I = \frac{M(T-H)\left(-\frac{\partial C_2{}^C}{\partial \tau_L} - C_2\frac{\partial H}{\partial I}\right)}{-\frac{\partial C_1{}^C}{\partial \tau_L} - \frac{\partial C_2{}^C}{\partial \tau_L} - (T-H)\frac{\partial H}{\partial I}}. \tag{a12}$$

Equation (a12) can be rewritten as the following:

$$\partial W^I = \frac{M(T-H)\left(-\frac{\partial C_2{}^C}{\partial \tau_L}\frac{(1-\tau_L)}{C_2}\frac{C_2}{(1-\tau_L)} - C_2\frac{\partial H}{\partial I}\frac{(1-\tau_L)(T-H)}{(T-H)}\frac{(T-H)}{(1-\tau_L)(T-H)}\right)}{-\frac{\partial C_1{}^C}{\partial \tau_L}\frac{(1-\tau_L)}{C_1}\frac{C_1}{(1-\tau_L)} - \frac{\partial C_2{}^C}{\partial \tau_L}\frac{(1-\tau_L)}{C_2}\frac{C_2}{(1-\tau_L)} - (T-H)\frac{\partial H}{\partial I}\frac{(1-\tau_L)(T-H)}{(T-H)}\frac{(T-H)}{(1-\tau_L)(T-H)}} \tag{a13}$$

Multiplying equation (a13) by $(1-\tau_L)$ gives:

$$\partial W^I = \frac{MC_2(C_1+C_2)(n_{C2H}{}^C + n_{LI})}{n_{C1H}{}^C C_1 + n_{C2H}C_2 + n_{LI}(C_1+C_2)}, \tag{a14}$$

where

$$n_{C2H}{}^C = \frac{\partial C_2{}^C}{\partial \tau_L}\frac{(1-\tau_L)}{C_2};\; n_{C1H}{}^C = \frac{\partial C_1{}^C}{\partial \tau_L}\frac{(1-\tau_L)}{C_1};\; n_{LI} = \frac{\partial H}{\partial I}\frac{(1-\tau_L)(T-H)}{(T-H)}. \tag{a15}$$

Dividing by $(C_1+C_2)$, we obtain:

$$\partial W^{I} = \frac{MC_2(n_{C2H}{}^{C} + n_{LI})}{n_{C1H}{}^{C}\,\frac{C_1}{C_1 + C_2} + n_{C2H}\,\frac{C_2}{C_1 + C_2} + n_{LI}}, \tag{a16}$$

or

$$\partial W^{I} = \phi_C MC_2, \tag{a17}$$

where

$$\phi_C = \frac{(n_{C2H}{}^{C} + n_{LI})}{n_{C1H}{}^{C}\,\frac{C_1}{C_1 + C_2} + n_{C2H}{}^{C}\,\frac{C_2}{C_1 + C_2} + n_{LI}}. \tag{a18}$$

# Appendix B: Corresponding Macro Functions

*Macros for Non-Energy Producing Sectors*

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*        Top Level
(6.2.8)   $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)))
(6.2.9)   $macro   qvae_ces(a)   (QX(a)/ADX(a))*(ADX(a)*deltaqx(a)*PX(a)*(1-TX(a))/PVAE(a))**elx(a)
(6.2.10)  $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
(6.2.11)  $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)))
(6.2.12)  $macro   qvke_ces(a)    (QVAE(a)/ADVAE(a))*(ADVAE(a)*deltavae(a)*PVAE(a)/PVKE(a))**elvae(a)
(6.2.13)  $macro   qvll_ces(a)      (QVAE(a)/ADVAE(a))*(ADVAE(a)*(1-deltavae(a))*PVAE(a)/PVLL(a))**elvae(a)

*        Third Level
(6.2.14)  $macro   pvll_ces(a)       (1/ADVLL(a))*SUM(f$deltavll(f,a), deltavll(f,a)**elvll(a)*(WF(f)*WFDIST(f,a)*(1+TF(f,a)))**(1-elvll(a)))**(1/(1-elvll(a)))
(6.2.15)  $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
(6.2.16)  $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)))
(6.2.17)  $macro   qve_ces(a)        (QVKE(a)/ADVKE(a))*(ADVKE(a)*deltavke(a)*PVKE(a)/PVE(a))**elvke(a)
(6.2.18)  $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
(6.2.19)  $macro   pve_cd(a)        (1/adve(a))*(PVEL(a)/rhocel(a))**rhocel(a)*(PVNEL(a)/rhocnel(a))**rhocnel(a)
(6.2.20)  $macro   qvel_cd(a)        rhocel(a)*QVE(a)*PVE(a)/PVEL(a)
(6.2.21)  $macro   qvnel_cd(a)      rhocnel(a)*PVE(a)*QVE(a)/PVNEL(a)

*           Fifth Level
(6.2.24)  $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)))
(6.2.25)  $macro   qvco_ces(a)      (QVNEL(a)/adnel(a))*(adnel(a)*deltanel(a)*PVNEL(a)/PVCO(a))**elnel(a)
(6.2.26)  $macro   qvnco_ces(a)     (QVNEL(a)/adnel(a))*(adnel(a)*(1-deltanel(a))*PVNEL(a)/PVNCO(a))**elnel(a)

*           Sixth Level
(6.2.29)  $macro   pvnco_cd(a)       (1/adnco(a))*prod(c$coaln(c), ((PQD(c)*(1+TEG(c,a))*PQDDIST(c,a) + TCARB(c,a))/rhocnco(c,a))**rhocnco(c,a))
(6.2.30)  $macro   qintd_cd(c,a)      rhocnco(c,a)*QVNCO(a)*PVNCO(a)/(PQD(c)*(1+TEG(c,a))*PQDDIST(c,a) + TCARB(c,a))
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*Macros for Energy Producing Sectors*

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*       Third Level
(6.2.31)  $macro   pvke_leon(a)      (QVE(a)*PVE(a)+ FD("fCap",a)*WF("fCap")*WFDIST("fCap",a)*(1+TF("fCap",a)))/QVKE(a)
(6.2.32)  $macro   qve_leon(a)       ioqve(a)*QVKE(a)
(6.2.33)  $macro   fdcap_leon(a)     ioqcap(a)*QVKE(a)

*       Fourth Level
(6.2.34)  $macro   pve_leon(a)      SUM(c$ceg(c), ((PQD(c) + TCARB(c,a))*(QINTD(c,a)))/QVE(a)
(6.2.35)  $macro   qintd_leon(c,a)   ioqenergy(c,a)*QVE(a)
```

*Macros for the Electricity Sector*

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*       Power Generation Technologies
(6.2.36)  $macro   pxe_ces(a)      (1/adtb(a))*sum(tb, deltatb(a,tb)**eltb*PXtb(a,tb)**(1-eltb))**(1/(1-eltb))
(6.2.37)  $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
(6.2.38)  $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))
(6.2.39)  $macro   qvaetb_ces(a,tb)  (QXtb(a,tb)/atbx(a,tb))*(atbx(a,tb)*dtbx(a,tb)*PXtb(a,tb)/PVAEtb(a,tb))**eltbx
(6.2.40)  $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
(6.2.42)  $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))
(6.2.43)  $macro   qvlltb_ces(a,tb)   (QVAEtb(a,tb)/atbvae(a,tb))*(atbvae(a,tb)*dtbvae(a,tb)*PVAEtb(a,tb)/PVLLtb(a,tb))**eltbvae
(6.2.44)  $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
(6.2.45)  $macro   pvlltb_ces(a,tb)   (1/atbvll(a,tb))*sum(f$(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))
(6.2.46)  $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
(6.2.47)  $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))
(6.2.48)  $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
(6.2.49)  $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
(6.2.52) $macro   pvetb_ces(a,tb)         (1/atbve(a,tb))*sum(c$ceg(c), dtbve(c,a,tb)**eltbve*((PQD(c) + TCARB(c,a))**(1-eltbve))**(1/(1-eltbve))
(6.2.53) $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*

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*       Top level
(6.2.57) $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)))
(6.2.58) $macro   qeh_ces(h)       (QHEXP(h)/ach(h))*(ach(h)*deltah(h)*PHEXP(h)/PEH(h))**(1/(1+rhoch(h)))
(6.2.59) $macro   qneh_ces(h)     (QHEXP(h)/ach(h))*(ach(h)*(1-deltah(h))*PHEXP(h)/PNEH(h))**(1/(1+rhoch(h)))

*       Second level
(6.2.60) $macro   peh_ces(h)        (1/aceh2(h))*sum(c$he(c), deltaeh(c,h)**elasteh(h)*(PQD(c) + TCARBH(c,h))**(1-elasteh(h)))**(1/(1-elasteh(h)))
(6.2.61) $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
(6.2.62) $macro   pneh_cd(h)       (1/acneh(h))*prod(c$hne(c),((PQD(c) + TCARBH(c,h))/comhav(c,h))**comhav(c,h))
(6.2.63) $macro   qcdhne_cd(h)    comhav(c,h)*QNEH(h)*PNEH(h)/(PQD(c) + TCARBH(c,h))
```

# Appendix C: Derivation of Perceived Elasticities of Demand

Demand function for domestically produced commodities (*QD$_c$*):

$$QD_c = \left(\frac{QQ_c}{ac_c}\right) * \left(ac_c * (1 - delta_c) * \frac{PQS_c}{PD_c}\right)^{\sigma_c} . \tag{c1}$$

Price index for the composite of commodities (*PQD$_c$*):

$$PQS_c = \frac{1}{ac_c} * \left(delta_c^{\sigma_c} * PM_c^{1-\sigma_c} + (1 - delta_c)^{\sigma_c} * PD_c^{1-\sigma_c}\right)^{\frac{1}{1-\sigma_c}} . \tag{c2}$$

Derive the demand function for domestically produced commodities (*QD$_c$*) with respect to the price of domestically produced commodities (*PD$_c$*):

$$\frac{\partial QD_c}{\partial PD_c} = \sigma_c * \left(-\frac{QD_c}{PD_c}\right) + \sigma_c * \frac{QD_c}{PQS_c} * \frac{\partial PQS_c}{\partial PD_c} + \frac{QD_c}{QQ_c} * \frac{\partial QQ_c}{\partial PD_c} . \tag{c3}$$

Multiply by $\frac{PD_c}{QD_c}$:

$$\frac{\partial QD_c}{\partial PD_c} * \frac{PD_c}{QD_c} = -\sigma_c + \sigma_c * \frac{PD_c}{PQS_c} * \frac{\partial PQS_c}{\partial PD_c} + \frac{PD_c}{QQ_c} * \frac{\partial QQ_c}{\partial PD_c} . \tag{c4}$$

Derive the price index for the composite of commodities (*PQS$_c$*) with respect to the price of domestically produced commodities (*PD$_c$*):

$$\frac{\partial PQS_c}{\partial PD_c} = \left(\frac{PQS_c}{PD_c}\right)^{\sigma_c} * (1 - delta_c)^{\sigma_c} * ac_c^{\sigma_c - 1} \tag{c5}$$

Substitute:

$$\frac{\partial PQS_c}{\partial PD_c} = \frac{QD_c}{QQ_c} . \tag{c6}$$

Apply the chain rule:

$$\frac{\partial QQ_c}{\partial PD_c} = \frac{\partial QQ_c}{\partial PQS_c} * \frac{\partial PQS_c}{\partial PD_c} \tag{c7}$$

to obtain:

$$\begin{aligned} DELdom_c = \frac{\partial QD_c}{\partial PD_c} * \frac{PD_c}{QD_c} &== -\sigma_c + \sigma_c * \frac{PD_c}{PQS_c} * \frac{QD_c}{QQ_c} \\ &+ \frac{PD_c}{QQ_c} * \frac{\partial QQ_c}{\partial PQS_c} * \frac{QD_c}{QQ_c} * \frac{PQS_c}{QQ_c} * \frac{QQ_c}{PQS_c} \end{aligned} , \tag{c8}$$

where *DELdom$_c$* is the perceived elasticity of demand. Rearrange and multiply by (-1):

$$DELdom_c = \sigma_c - SHarm_c * (\sigma_c + \frac{\partial QQ_c}{\partial PQS_c} * \frac{PQS_c}{QQ_c}), \tag{c9}$$

where $SHarm_c = \frac{PD_c}{PQS_c} * \frac{QD_c}{QQ_c}$ and $\frac{\partial QQ_c}{\partial PQS_c} * \frac{PQD_c}{QQ_c} = -1$.

# Erklärung

Hiermit erkläre ich, dass ich die Dissertation selbständig angefertigt habe. Nur die angegebenen Quellen wurden benutzt und wörtlich oder inhaltlich als solche gekennzeichnet. Darüber hinaus wurde die vorgelegte Dissertation bisher nicht im In- oder Ausland in dieser oder ähnlicher Form in einem anderen Promotionsverfahren vorgelegt. Die Promotion wurde im Rahmen ERASMUS MUNDUS Projektes gefördert.

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Anton Orlov