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The Kyoto Protocol without USA and Australia - with the Russian Federation as a strategic permit seller

Abstract:
After the U.S. and Australian withdrawal from the Kyoto Protocol, and the extension of national quotas in the Bonn- and Marrakesh-agreements, meager environmental effects and a low price of emission permits is likely to be the outcome of implementation. This paper provides an analysis of these prospects for the Kyoto Protocol and the international permit market based on different assumptions related to the baseline scenario. Possible strategic behavior in the permit market is emphasized: A contribution of the paper is to take into consideration potential conflicting Russian interests in the market for natural gas in Europe and the market for emission permits under the Kyoto Protocol. The Russian Federation is a large supplier with the potential for exercising market power in both these markets. The analysis shows that the Russian interests in the gas market may lead Russia to increase export of emission allowances and consequently contribute to a low permit price. The applied analytical tool is a partial equilibrium model of the market for emission allowances and the fossil fuel markets.

Keywords: Emissions trading, Permit price, Fossil fuel markets, Natural gas market, Kyoto Protocol, Market power.

JEL classification: Q30, Q41.

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1. Introduction and scope of the paper

The USA will not be a party to the Kyoto Protocol; at least as far as the first commitment period (2008-2012) is concerned. In other words; the potentially most important buyer in a future market for emission permits is out of the market. Australia, another likely permit demander, has also declared that ratification will not be carried out. At the same time the EU has accepted rules for free emissions trading while Russia, Ukraine, and some other countries in Eastern Europe have considerable amounts of hot air.[1] Consequently, these countries may sell large numbers of permits and cause a low permit price in the first commitment period. In other words, after the U.S. and Australian withdrawal the environmental output of the Kyoto Protocol might be insignificant. Ray J. Kopp (2001) characterizes the "Protocol without the U.S. as like musical chairs with one too many chairs - there's a lot of marching around, but nothing happens."

There are, however, some reasons why Russia and other countries with considerable amounts of hot air might restrict their permit sales and therefore cause a small but significant environmental output and permit price. Firstly, large permit sellers might want to restrict the sales in order to increase the permit price. Secondly, at the time of the first commitment period an agreement for a second commitment period might have been established and entered into force. Because the Protocol allows the parties to save unused emission permits (Assigned Amount Units, AAUs) to later periods, the seller countries will not accept prices that are considerably lower than the discounted value of the expected price in the second commitment period.[2]

It is, however, not obvious that it is in the interests of the Russian Federation to restrict its sales of emission allowances although it will increase the permit price. This is related to the Russian interests in the European gas market. Introduction of obligatory, tradable emission permits or emission taxes will increase the end user price of fossil fuels and should from that perspective cause reduced demand and lower producer prices of coal, oil and gas. However, because oil and coal combustion are more CO_2-intensive than gas there might be fuel switching towards natural gas. Numerical models are therefore necessary in order to evaluate which of these effects are the strongest. Unfortunately different numerical models give different results. While Bartsch and Müller (2000), Holtsmark and Mæstad (2002), and McKibbin et al. (1999) conclude that the European gas producer price will drop

[1] A country has 'hot air' to the extent that its national emission quota (Assigned Amount) is larger than its business-as-usual emissions.

[2] If the sellers are risk averse they may accept prices that are lower than the discounted expected permit price for the second commitment period.

as a result of the emerging permit market, MacCracken et al. (1999) conclude in the opposite direction. The result in Holtsmark et al. (2002) is especially related to the fact that in Western Europe end user taxes on oil products are on average higher than end-user taxes on gas. It is assumed that the current structure of fiscal fossil fuel taxation in Western Europe is sustained into the first commitment period of the Kyoto Protocol. Hence, as a permit price is added to the end-user prices, the relative increase in the average consumer price of oil relative to gas is smaller than implied by the underlying emission factors. Consequently, the introduction of a permit market in Western Europe should cause substitution from gas to oil. The robustness of this result is discussed in Holtsmark and Mæstad (2002). This paper applies a modified and improved version of the model used in Holtsmark et al. (2002) and focuses on how the mentioned substitution effects in the gas market are likely to influence the permit supply from FSU (Former Soviet Union). Because the Russian Federation not only is an important seller of emission permits, but also is the largest seller of gas to the European market, the Russian government may take its possibly conflicting national interests in these two markets into consideration.

A lot of work has been put into numerical analysis of the consequences of the Kyoto agreement for the world economy. A special issue of the Energy Journal (1999) provides a good overview of this literature. Closely related to this study are the papers by Bernstein *et al.* (1999), MacCracken *et al.* (1999), and Bollen *et al.* (1999). However, these papers do not take the U.S. and Australian withdrawal into account. The U.S. withdrawal is emphasized in Hagem and Holtsmark (2000), Böhringer (2002), Böhringer and Löschel (2003), and den Elzen and de Moor (2003)[3]. Hagem and Holtsmark (2000) apply a simplified version of the model used in this paper. In the simplified model strategic behavior in the European gas market and the permit market was not included. Böhringer (2002) applies a CGE-model of the world economy, while Böhringer and Löschel (2003) applies a partial equilibrium model with estimated marginal abatement cost curves. Böhringer (2002) and Böhringer et al. (2003) conclude that after U.S. withdrawal the Kyoto Protocol more or less boils down to business-as-usual. However, Böhringer (2002) and Böhringer et al. (2001) investigate effects of monopolistic permit supply from the countries in transition to a market economy and show that the Protocol might after all cause some emission reductions, although small. This is in line with the conclusions in den Elzen et al. (2003) who, as Böhringer et al. (2003), apply a partial equilibrium model of the permit market where the abatement costs are derived from an applied general equilibrium model. A contribution of den Elzen et al. (2003) and Böhringer et al. (2003) is to show that the permit price and the environmental effectiveness of the Kyoto Protocol to a large extent is determined by the

[3] These three papers take U.S. withdrawal, but not Australian withdrawal, into account.

behaviour of the Russian Federation and other industrialized countries in transition to a market economy. While Böhringer et al. (2003) formally investigate strategic behaviour in the permit market, den Elzen et al. (2003) draw attention to the possibility for banking.

While den Elzen et al. (2003) and Böhringer et al. (2003) apply simple partial equilibrium models of the permit market, this paper apply a partial equilibrium model of the permit market *and* the fossil fuel markets. The model applied here is constructed in order to incorporate the important links between the international permit market and the fossil fuel markets. The applied model has not explicit abatement cost functions as in den Elzen et al. (2003) and Böhringer et al. (2003) because such explicit abatement cost functions overlook the important links between abatement costs and equilibrium effects in the energy markets. In this paper the starting point is therefore instead a model of the international markets for oil and coal and the regional markets for natural gas. The demand and supply of fossil fuels give rise to the demand and supply of emission allowances and implicitly abatement costs as lost 'consumers surplus'. It is not least important that the model include three regional gas markets in order to realistically take into account how the equilibrium effects from the fossil fuel markets are different in Western Europe, North-America and the Pacific region. The inclusion of a regional market for gas in Europe is furthermore important in an analysis of Russian behaviour. This feature of the applied model gives the possibility for an investigation of the interests and behavior of FSU as a possible cartel in the permit market when Russian interests in the European gas market is taken into consideration.

The paper is also supplemental to the papers by Böhringer et al. in relation to the fact that CDM is included in the analysis. The paper will show the importance of including CDM in an analysis of the effects of strategic behavior in the permit market. Furthermore, the present paper is updated in the sense that the Australian withdrawal from the Protocol is taken into consideration and it provides an updated numerical analysis of the emerging market for emission allowances under the Kyoto Protocol based on the scenarios for fossil fuel consumption in International Energy Outlook (DOE 2002) from the Energy Information Administration, U.S. Department for Energy. DOE 2002 provides High growth and Low Growth scenarios in addition to the Reference scenario. The analysis provides estimates of the price and trade movements in permit market as well as the environmental output of the Kyoto Protocol under all the three scenarios. The application of all three scenarios gives some ideas of the degree of uncertainty of the price estimates. Furthermore, the degree of uncertainty is investigated by presentation of sensitivity analyses with respect to the applied elasticities of demand for fossil fuels.

The applied numerical model is further described in Appendix A, cf. also Holtsmark and Mæstad (2002). The applied version of the model divides the world into 12 regions, of which FSU, USA, EU and OPEC are the most important, cf. the complete list of region/countries in for example Table 1. Demand and supply functions for oil, coal and gas are specified for each region. The model assumes that efficient markets for emission permits are established in countries with binding emission caps in the Kyoto Protocol. This implies that fossil fuel consumers will pay a carbon-related permit price on the top of the producer prices and end-user taxes in these countries.

The paper is organized as follows: The next section gives an overview of the model. The third section describes the special structure of the market for emission allowances under the Kyoto Protocol. The fourth section provides an overview of the three applied baseline scenarios of the fossil markets. The fifth section applies the model in order to provide scenarios for the market for emission allowances. The sixth section provides some sensitivity analyses. The seventh section concludes. Three appendixes give an overview of the numerical model, the applied data sets and the calibration method as well as some further model simulation results.

2. Description of the model

The emission restrictions in the Kyoto Protocol apply to CO_2 and five other greenhouse gases and groups of greenhouse gases. Unfortunately emission data on the non-CO_2-gases are often unavailable. Therefore this paper, as most of the literature in the field, ignores the non-CO_2-gases. This simplification represents a source of inaccuracy, but it is difficult to say in which direction.

The paper applies a static partial equilibrium model that emphasizes the links between the fossil fuel markets and a market for emissions permits under the Kyoto Protocol.[4] The version of the model used here divides the world into 12 countries/regions, cf. Table 1. In each country or region, a numeraire good is produced using three inputs: oil, coal, and gas. The three fossil fuels are modeled as substitutes in the demand functions. The assumed production technology yields a linear demand function for all inputs. The consumer prices are equal to the sum of producer prices, end-user taxes and the price of emission permits.

There are five markets for fossil fuels in the model: one global oil market, one global coal market, and due to high transport costs: three regional gas markets (North America, Europe including the Russian Federation and Algeria, and the Pacific region). In an analysis of the permit market it turns out to be

[4] A more detailed description of the model is provided by Appendix A. Some other applications of the models are found in Holtsmark (1997), cf. also Holtsmark and Mæstad (2002).

essential to split the gas market into three regional markets, not least in an analysis of the Russian roles as both permit seller and seller of natural gas. Furthermore, the leakage- and substitution effects in the fossil fuel markets depend to a large degree to what extent the markets are international or regional.

The model includes an international market for emissions permits covering the industrialized countries with emissions caps under the Kyoto Protocol. In case 3, 4, and 6 this market is global in order to take CDM into consideration. CDM is included in the model by assuming that the developing countries have caps equal to their BAU-emissions.

The gas markets in North America and Pacific and the international coal market are assumed to be competitive. In the European gas market, the oil market and the market for emission permits it would be unrealistic to ignore exertion of market power. In the oil market it is therefore assumed that OPEC behaves strategically (acts as a dominant seller) and restricts its oil supply in order to maximize its net revenue while all other suppliers are price takers (a competitive fringe).[5] Furthermore, in the European gas market the Russian Federation is correspondingly assumed to be a dominant seller and price setter while other suppliers (the fringe) are price takers. Concerning the market for emission permits this market is as a starting point assumed to be competitive. Analyses are later on performed related to Russian exertion of market power also in the permit market.

The model determines equilibrium prices in the fuel markets and the market for emissions permits as well as the different countries' and regions' export and import of fossil fuels and emission permits.

The model is calibrated to three "business as usual" (BAU) scenarios of world energy markets in year 2010. The three BAU-scenarios are based on the three scenarios in International Energy Outlook (DOE) 2002. Some other data sources are also used, cf. Appendix B.

The formulation of the model imply that the abatement costs follow implicitly from parameters of the demand functions which on their side follows from the price elasticities and composition of the demand for each fuel in each country. There is no consensus in the literature about own-price demand elasticities in fossil fuel markets, cf. Smith *et al.* (1995), Brubakk et al. (1995), Franzen and Sterner (1995). However, Aune et al. (2002) provide a thorough discussion of the relevant literature. In lack of decisive evidence, I have as a starting point chosen a middle road assuming average own-price

[5] OPEC is assumed to have constant marginal costs while all other suppliers have increasing marginal costs. In the European gas market FSU correspondingly has constant marginal costs while the other producers have increasing marginal costs, cf. Appendix A.

elasticities of –0.5 for all fossil fuels. By using detailed information from the IEA (1995) the various elasticities are then adjusted as further described in Holtsmark and Mæstad (2002). Finally, dividing or multiplying the elasticities by 2 complete the sensitivity analyses with respect to the demand elasticities.

Table 1. Assumed demand own- and cross-price elasticities for oil (1), coal (2) and natural gas (3)

	ε_{11}	ε_{12}	ε_{13}	ε_{21}	ε_{22}	ε_{23}	ε_{31}	ε_{32}	ε_{33}
U.S.	-0.33	0.03	0.08	0.16	-0.66	0.15	0.16	0.07	-0.40
Canada	-0.47	0.02	0.08	0.14	-0.60	0.18	0.15	0.04	-0.42
Western Europe	-0.50	0.01	0.06	0.26	-0.56	0.16	0.16	0.02	-0.36
Norway	-0.54	0.00	0.04	0.19	-0.02	0.19	0.19	0.02	-0.65
FSU	-0.78	0.05	0.15	0.20	-0.54	0.18	0.08	0.02	-0.90
EIT	-0.70	0.08	0.13	0.18	-0.56	0.10	0.13	0.05	-0.90
Algeria	-0.50	0.00	0.11	0.33	-0.50	0.20	0.04	0.00	-0.50
OPEC	-0.50	0.00	0.11	0.62	-0.50	0.20	0.12	0.00	-0.50
Japan	-0.65	0.02	0.04	0.17	-0.35	0.15	0.22	0.07	-0.51
New Zealand	-0.19	0.01	0.10	0.37	-0.29	0.19	0.26	0.02	-0.62
Australia	-0.29	0.04	0.08	0.24	-0.61	0.14	0.33	0.11	-0.52
Rest of the World	-0.71	0.13	0.06	0.43	-0.38	0.04	0.14	0.03	-0.56

As for fuel supply, it is generally recognized that the supply of coal is more elastic than the supply of other fuels. I have followed Golombek and Bråten (1994) by assuming supply elasticities of 2.0 for coal producers and 1.0 for both competitive gas producers and oil producers. Gas supply from FSU and oil supply from OPEC are not determined by explicit supply functions, but through formation of cartels that are exerting their market power in the respective markets.

3. The structure of the market for emission allowances under the Kyoto Protocol

The Marrakech Accords define four different types of emission allowances. Firstly, an Assigned Amount Units (AAU) gives the right to emit one tonne of CO_2 in the period 2008-2012. Each country with an emission cap is eligible to issue a number of AAUs equal to its Assigned Amount specified in Annex B of the Protocol. The parties are free to transfer or import AAUs, if it is in compliance with a number of requirements. AAUs could also be banked to a future commitment period.

Second, Emission Reduction Units (ERUs) are issued after application of the Joint Implementation mechanism. The host country, which is an industrialized country, should issue and transfer to the investor a number of ERUs according to the attained emission reductions while a corresponding number for AAUs in the host country are deleted. In this study Joint Implementation and ERUs are not further discussed. The reason is that in a simplified model framework ordinary trade with AAUs makes JI and ERU-trade redundant.

Third, Certified Emission Reductions (CERs) are accrued credits from emission reduction projects carried out in developing countries through the Clean Development Mechanism (CDM).

Fourth, Removal Units (RMUs) are issued in relation to carbon sequestration activities (land-use, land use change and forestry, LULUCF). There are no constraints on generating RMUs from afforestation, reforestation, and deforestation activities. Hence, in order to minimize the cost of the agreement, the Parties would take advantages of these carbon-sequestration possibilities and carry out activities for which the costs are less than reducing their emissions of greenhouse gases. Since the applied model does not include the possibilities for carbon sequestration the permit price might in that respect to some extent be slightly overestimated.

Although there are no constraints on generating RMUs from afforestation, reforestation, and deforestation activities, a ceiling on eligible forest management activities is specified for each industrialized country. In total the industrialized countries are permitted to issue 256 million RMUs from forest management activities of which the Russian Federation and Canada may issue 121 and 44 million RMUs respectively.

It is commonly argued that carbon sequestration through forest management, within the limits of the specified ceilings, would occur even without the Kyoto Protocol. If this is the case, RMUs generated from forest management is a "no-regret" option that do not lead to any real net emission reductions compared to the "Business-as-Usual" scenario. The applied national quotas are therefore in this paper extended in order to include the ceiling on eligible forest management activities.

It has often been argued that CDM to some extent will be a loophole, which, due to control problems, might give a considerable supply of low-cost CERs into the market that are not really based on emission reductions. In that case, the CDM mechanism leads to less global emission reductions. (See inter alia Bohm (1994) and Hagem (1996) for a discussion of the possible adverse impact of CDM on global emissions). In this paper this possibility is ignored. Instead it is simply assumed that all CERs that are sold on the market have a corresponding emission reduction effect.

4. An overview of the applied scenarios

The baseline scenarios are crucial in any assessment of the prospects of the market for emission allowances under the Kyoto Protocol. In this section the applied baseline scenarios are therefore described.

The three scenarios in the International Energy Outlook 2002 from the U.S. Department of Energy (DOE) constitute the basis of the constructed baselines. Some key data are presented in table 2. The DOE-data on 1990-emissions constitutes the basis for calculation of the different region's quotas under the Kyoto Protocol. These data are somewhat different from other data sources, for example the numbers on page 33-34 in the official print of the Kyoto Protocol. In this study the DOE-data are nevertheless chosen as basis for calculation of the quotas in order to have a consistent data set.

Table 2 is useful for a comparison of the predicted 2010-emissions with the aggregated national quotas. The corresponding differences between the baseline emissions and the national/regional quotas, which constitute the required cutbacks without emissions trading, are presented in table 3. In the following analysis the focus is towards cases where USA and Australia are not parties to the Protocol. The analysis is furthermore based on the extended quotas from the Marrakesh Accords including RMUs from non-regret forest management.

The predicted 2010-emissions in the Annex B region excl. USA and Australia is 8820 mill. tonnes CO_2 in the Reference scenario. On the other hand, the sum of the corresponding national quotas is 8854 mill. tonnes CO_2, if the extended quotas from the Marrakesh Accords on forest management crediting are taken into account. Hence, the sum of the quotas is larger than the BAU-emissions in the Reference scnenario, cf. table 3. On the other hand, in the High growth scenario there is a net cutback requirement of 510 mill. tonnes CO_2, which constitutes 2 percent of the global emissions. In the Low Growth scenario there is a surplus of 660 mill. AAUs. This means that in the Reference scenario and in the Low Growth scenario there will be a positive permit price only if the sellers restrict their sales in order to exert market power and/or to save emission allowances for future commitment periods.

Table 2. 1990-emissions, 2010-emissions, percentage cutbacks and quotas. Mill. tonnes CO_2

	1990-emissions	2010-emissions Reference	High growth	Low growth	Kyoto cutback (per cent)	Original quotas	Extended quotas
USA	4957	6725	6919	6582	93.0	4610	na
Canada	462	634	671	598	94.0	434	478
Western Europe	3376	3784	3967	3604	92.0	3106	3127
Norway	34	48	48	48	101.0	34	36
FSU	3047	2193	2393	1972	99.8	3042	3169
EE	1104	854	917	781	92.9	1025	1038
Japan	986	1258	1316	1144	94.0	927	975
New Zealand	28	50	52	46	100.0	30	31
Australia	294	434	450	405	108.0	316	316
Non-Annex B	7077	13024	15189	11620			
World	21366	29003	31922	26800			
Annex B	14289	15979	16733	15179	94.7	13526	-
Annex B ex. USA/Australia	9037	8820	9364	8193	95.2	8600	8854

Source: DOE 2002

Table 3. Absolute required cutbacks. Mill. tonnes CO_2

	Original quotas			Extended quotas		
	Reference	High growth	Low growth	Reference	High growth	Low growth
USA	2 114	2 309	1 971			
Canada	200	237	163	156	193	119
Western Europe	677	861	498	657	840	477
Norway	14	14	14	12	12	12
FSU	-849	-649	-1 070	-976	-776	-1 197
EE	-171	-109	-244	-184	-121	-257
Japan	331	389	217	283	342	169
New Zealand	19	22	16	19	21	15
Australia	118	134	89	118	134	89
Annex B	2 453	3 207	1 653			
Annex B ex. USA/Australia	220	764	-407	-33	510	-660

5. Prospects of the market for permits

There are different ways the Kyoto Protocol may be implemented. Five cases are therefore here defined and analyzed. In all cases the U.S. and Australian withdrawal is taken into account. Furthermore, all cases take into account the extension of national quotas related to possibilities for acquiring credits from non-regret options in forest management, which was a part of the Bonn- and the Marrakech agreements, cf. table 3.

Table 4. Characteristics of the different cases

Case	FSU acts strategically in the permit market	CDM is included in the model	FSU maximises sum of income from gas and permit market
1			
2	✓		
3	✓	✓	
4	✓		✓
5	✓	✓	✓

Table 4 provides an overview of the characteristics of the different cases. In case 1 the permit market is competitive. Furthermore, case 1 does not it include the Clean Development Mechanism. Case 2 extends case 1 by assuming that FSU acts strategically in the permit market, while case 3 extends case 2 by inclusion of CDM.

The cases 4 and 5 are slight modifications of the cases 2 and 3, respectively. In all these four cases FSU acts strategically in the permit market and the European gas market. In case 2 and 3, however, FSU does not take into consideration that permit sales might affect the gas price, and the other way around. This is taken into consideration in case 4 and 5 where FSU regulates gas production and permit sales in a way that maximizes the sum of revenue from the permit market and the European gas market.

In case 3 and 5 CDM is included in the numerical analysis simply by assuming that non-Annex B-countries have assigned amounts (national emission quotas) equal to their BAU-emissions and are free to take part in emissions trading. It is uncertain whether such modeling of CDM represents an overestimation or underestimation of total abatement carried out under this mechanism. A key question is how the rules for project-approval will be practiced. On the other hand, to ignore the mechanism, as is done in case 1, 2 and 4, certainly represents an underestimation of the supply of emission allowances. Nevertheless, it could be convenient for the reader to isolate the effects of the CDM-model. That is the reason why the cases 1, 2, and 4 do not include CDM.

The calculated permit price in the different cases and scenarios are presented in table 5 while the movements in the market for permits in the Reference scenario are presented in table 6. In the following discussion the different cases are analyzed with respect to the three BAU-scenarios described in the previous section. However, if nothing is said the discussion is related to the Reference scenario.

Table 5. Permit prices. USD/ton CO_2

	Case				
Scenario:	1	2	3	4	5
Reference	0.0	11.2	4.0	6.8	3.9
High Growth	7.4	14.6	5.0	10.1	4.8
Low Growth	0.0	6.9	2.6	2.6	2.4

Table 6. Net permit imports in the Reference scenario. Mill. tonnes CO_2

	Case				
	1	2	3	4	5
Canada	156	103	138	124	139
Western Europe	669	440	592	530	595
FSU	-939	-446	-470	-639	-487
Eastern Europe	-184	-304	-224	-257	-223
Japan	279	189	249	224	250
New Zealand	19	18	18	18	18
Non-Annex B	0	0	-303	0	-292
Annex B	0	0	303	0	292

Table 7. Emission reductions in the Reference scenario. Mill. tonnes CO_2

	Case				
	1	2	3	4	5
World	0	485	457	294	440
U.S.	0	-22	-22	-14	-21
Canada	0	53	18	32	17
Western Europe	0	229	77	139	74
FSU	0	-11	-7	-8	-7
Eastern Europe	0	121	41	73	39
Japan	0	90	30	55	29
New Zealand	0	1	0	1	0
Australia	0	51	17	31	16
Non-Annex B	0	-26	303	-16	292
Annex B incl USA	0	511	153	310	148
Annex B excl. USA	0	533	176	323	169

Firstly we turn to case 1, the only case which assumes a competitive permit market. In both the Reference scenario and the Low Growth scenario there is an excess supply of permits which gives a zero permit price and consequently no emission reductions. In the High Growth scenario there is excess demand of 510 mill. tonnes CO_2 which gives market equilibrium at a permit price of 7,4 USD. The global emission reduction is estimated to be 502 mill tonnes CO_2 in this case/scenario. This means that the model estimate an 8 mill. tonnes carbon leakage to the USA, Australia and the non-Annex B-countries.

Case 1 illustrates among other things to what extent the permit price and the environmental effect are sensitive to assumptions on baseline emissions. Hence, since the baseline emissions are uncertain the permit price and emission reductions are also difficult to predict. A global emission reduction of 502 mill. tonnes CO_2, or 1.9 per cent, is small, but not entirely insignificant.

In the Reference and Low Growth scenarios applied to case 1 there is trading in the permit market despite the price is estimated to zero. This is a self-contradiction because it is impracticable to have comprehensive permit trading at a zero permit price. No country will be selling permits without any benefits. This underlines the importance of modeling strategic behavior in the permit market. In case 2 it is therefore assumed that FSU acts as a cartel in the permit market and restricts its sale in order to maximize the income from permit sales. In the Reference scenario this gives a permit price of 11.2 USD pr tonnes CO_2. A model simulation not further described in this paper, which includes Australia as a country with an emission cap, gives a corresponding permit price of 11.6 USD/tonnes CO_2. In comparison Böhringer et al. (2003) have a permit price of 8.7 USD/tonnes in their matching case. The 2.9 USD difference in permit price estimates should at least partly be explained bye the use of different baseline scenarios. The model simulations in Böhringer et al. (2003) are based on the 2001 scenario from U.S. Department of Energy, while this paper applies the 2002 scenarios. In the 2002 scenario the emission growth estimates are adjusted slightly upwards compared to the 2001-scenario. The permit price estimate of case 2 could not be compared to the permit price estimates in den Elzen et al. (2002) because den Elzen includes permit supply from CDM in there analysis.

Case 3 extends case 2 by including CDM. This basically represents increased supply of emission allowances on the market. We consequently observe a price drop from 11.2 USD to 4.0 USD in the Reference scenario. If Australia complied with its original commitment the permit price would have been 4.4 USD/tonnes CO_2. The corresponding price estimate in den Elzen et al. (2002) is 3.2 USD/tonnes CO_2. The FSU hot air export is curtailed by about 50 per cent, cf. table 6. In den Elzen et al. (2002) the FSU hot air export is reduced by about 40 per cent as FSU maximises its revenue from permit sales.

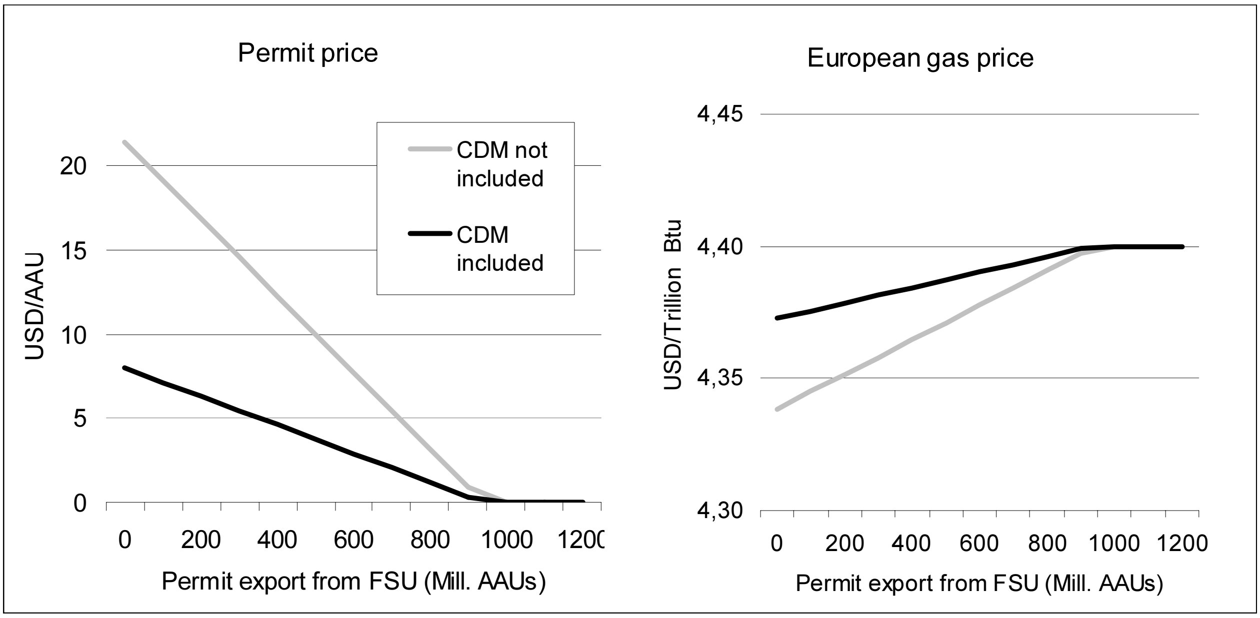
If we compare the price estimates in case 2 and 3, i.e. with and without CDM included, it is evident that an important effect of CDM is to reduce uncertainty with respect to the permit price. In case 2 (witout CDM) the difference between the lowest and highest price estimates is 7.7 USD. In case 3 (with CDM) the corresponding difference is only 2.4 USD.

Table 7 shows the emission reductions in the different cases. The negative numbers (increased emissions) is carbon leakage and deserve a comment. The relevant mechanism in the model is firstly that the emissions are slightly increased in countries without emissions caps when the countries with caps carry out abatement. This carbon leakage is due to reduced fossil fuel prices in the new equilibriums. The same effect is also reflected in table 8 when emission reductions on the global level are smaller than within Annex B excl. USA and Australia. Secondly, in the cases where FSU acts strategically in the permit market the emissions are also increased in FSU. This mirrors that the FSU in these cases are not subject to a binding commitment because only a part of the stock of AAUs reflecting hot air are sold on the market. Hence, no abatement policy is implemented in FSU and consequently there will be some carbon-leakage in this region due to lower fossil fuel prices.

Table 8. Regional and global emission reductions in the different scenarios and cases. Mill. tonnes CO_2

		Case				
	Scenario	1	2	3	4	5
World	Reference	0	485	457	294	440
	High growth	502	666	628	459	611
	Low Growth	0	276	261	101	245
Annex B incl. USA/Australia	Reference	0	511	153	310	148
	High growth	528	703	201	485	195
	Low Growth	0	290	93	107	87
Annex B excl. USA/Australia	Reference	0	533	176	323	169
	High growth	548	732	229	505	223
	Low Growth	0	304	106	112	100

Figure 1: The permit price and the price in the European gas market as the permit export from FSU is varied.



Because there are strong links between the permit market and the European gas market, it is a question whether a high permit price is in the interest of the Russian Federation. The links between these two markets should therefore be analyzed further. The right diagram of figure 1 shows how the price in the European gas market is influenced by increased supply of permits from FSU, according to the applied model. At the point where the permit export from FSU exceeds 939 mill. tonnes CO_2 there is excess supply and zero permit price. No abatement is carried out in any country and consequently we have returned to business-as-usual, cf. the horizontal gas price curve from that point.

The reason why the gas price increases as permit supply is increased is related to the assumed structure of fiscal taxation of fossil fuels in Europe, cf. table B.4 in Appendix B. It is here assumed that the current structure of these taxes is sustained which means low fiscal taxation of gas consumption and on average higher fiscal taxes on oil consumption in Western Europe. A permit price or a carbon tax on fossil fuels on top of the fiscal taxes and producer prices will then represent a higher relative increase of the consumer price of natural gas than oil in this area. Although also fiscal coal taxes are assumed to be sustained at a low level in Western Europe, the model simulations indicate that an increased permit price after all will cause substitution from gas to oil. For a discussion of this substitution effect including sensitivity analyses with respect to cross price elasticities, see Holtsmark and Mæstad (2002). From this follows that an 'one-eyed' strategic behavior in the permit market not necessarily is in the interests of FSU. The effect is still significant, although weaker if CDM is taken into consideration, cf. figure 1. CDM causes a lower permit price and a corresponding smaller substitution effects in the fossil fuel markets. Nevertheless, this indicates that Russian interests in the European gas market might cause increased supply on the permit market.

The issue is further illuminated by case 4 and 5, which are adjusted versions of case 2 and 3, correspondingly. In all these four cases FSU acts strategically in both the permit market and the natural gas market. In case 4 and 5, however, FSU maximizes the sum of net income in the permit market and the gas market, or in other words, performs a coordinated strategic behavior in these two markets. In case 2 and 3, in contrast, FSU carry out an uncoordinated strategic behavior in the two markets. While case 2 and 4 do not include CDM in the model, CDM is included in case 3 and 5, cf. table 4.

Table 9 shows the export of AAUs in the different cases and scenarios while the corresponding permit prices are given in table 5.

As a starting point we should compare case 2 and 4, where CDM is not taken into account. Basically a co-ordinated strategy in the two markets means here a considerable increased supply of permits from FSU and a corresponding price drop of around 4 USD. This is, however, based on the cases where CDM is ignored. If we compare case 3 and 5, where CDM is included, the coordinated strategy has only a small effect on the permit supply, cf. table 9. The price drop in the permit market is correspondingly small. This result is explained by the fact that the permit price is at a considerably lower level when CDM is taken into consideration. A lower permit price means that the effects on gas demand is smaller and consequently less able to alter the profit-maximising behaviour of the FSU in the gas market.

Table 9 Permit export from FSU to Europe. Million AAUs

	Case				
Scenario	1	2	3	4	5
1	939	446	470	639	487
2	953	612	645	821	663
3	536	255	268	431	285

After all it could be reasonable to emphasize the cases that include CDM and where FSU acts strategically in the permit market. That means that we should rely on the results of case 3 and/or 5. Regardless of choice of BAU-scenario the permit price estimates is then within the range of 2.7 to 5.2 USD/AAU. The permit price is only slightly higher if FSU has a coordinated strategy towards the gas market and the permit market.

6. Sensitivity analyses

The applied demand elasticities given in table 1 are important for the results presented in the previous section. It is therefore relevant to have a look at the consequences of other assumptions at this point. In two model simulations the demand elasticities are divided and multiplied by 2 respectively. Different demand elasticities will influence the carbon leakage, but will otherwise not influence the environmental output of the Protocol. In the following the focus is therefore on how the demand elasticities influence the permit price.

Table 10 presents the simulated permit prices as the originally applied demand elasticities are divided by 2. The permit prices are then almost doubled in all cases and scenarios, except in the Reference and Low growth scenarios, case 1. In these two cases/scenarios there is excess supply of permits and only price-takers in the permit market. Hence, the permit price is zero irrespective of the demand elasticities. In the High growth scenario and case 1 (no CDM and only price-takers in the permit market), the permit price almost doubles from 7.4 to 14.5 USD, cf. table 10. This is also the general picture of the effects of dividing the demand elasticities by 2: The permit price is almost doubled in all cases/scenarios.

Table 10. Permit price when all demand-elasticities are divided by 2. USD/AAU

	Case				
	1	2	3	4	5
Reference	0.0	21.7	7.7	14.9	7.4
High Growth	14.5	28.2	9.5	21.2	9.3
Low Growth	0.0	13.2	5.0	6.6	4.7

Table 11 shows the simulated permit price if the demand elasticities are doubled relative to the baseline elasticities. The result is that the permit prices are almost halved.

Table 11. Permit price when all demand-elasticities applied are doubled. USD/AAU.

	Case				
	1	2	3	4	5
Reference	0.0	5.9	2.1	3.2	2.0
High Growth	3.8	7.7	2.6	4.9	2.6
Low Growth	0.0	3.6	1.4	1.0	1.3

The sensitivity analyses with respect to the demand elasticities show that the permit price estimates are highly sensitive to these elasticities. This underlines to what extent it is difficult to predict the permit price. Nevertheless, if CDM is included in the analysis the price estimates are in the range 1-10 USD even when the demand elasticities are varied considerably.

In the previous section focus was put on the permit export from FSU. This is followed up in table 12, which shows the permit export from FSU in the Reference scenario as the different elasticity factors are applied. The general picture is that permit export from FSU is relatively insensitive to the general level of the demand elasticities in the fossil fuel markets. The reason is that not only the demand side of the permit market is affected as the elasticities are varied. Also the demand elasticities for fossil fuels within FSU is divided or multiplied by 2. That means that the implicit marginal abatement costs in FSU, which is crucial for the permit export, is made more or less steep, respectively. Hence, as the demand elasticities are either divided or multiplied by 2, the demand and supply of permits is influenced in a symmetric way.

Table 12. Permit export from FSU in the Reference scenario

	Case				
Elasticity factor:	1	2	3	4	5
0,5	939	456	470	608	484
1	939	446	470	639	487
2	939	430	470	668	490

7. Conclusions

After the U.S. withdrawal from the Kyoto Protocol a meager environmental effect and a low permit price is likely to be the outcome of implementation of the Protocol. This has already been concluded in among others Hagem et al. (2001) and Böhringer (2002). This paper has analysed further the prospects of the permit market and the environmental effects of the Kyoto Protocol taking into account that it now seems likely that also Australia has withdrawn its participation in the Kyoto Protocol.

The Russian Federation, Ukraine, and other parties that earlier belonged to Soviet Union, have assigned amounts that are considerably larger than their likely business-as-usual-emissions in the first commitment period of the Kyoto Protocol. This paper have therefore emphasized cases where the Former Soviet Union (FSU) acts as a dominant seller in the permit market. In line with Böhringer et al. (2003) and den Elzen et al. (2003) I found that FSU as a dominant seller is likely to restrict its permit export and consequently increase the permit price and the environmental output of the Kyoto Protocol. The price estimates presented in this paper are 3 - 4 USD higher than the corresponding price estimates in the papers by Böhringer et al. (2003) and den Elzen et al. (2003). The difference is to a large part explained by the use of the most recent emission scenarios from U.S. Department of Energy, which have adjusted the emission growth slightly upwards compared to the scenarios used by Böhringer et al. (2003).

A contribution of the paper is to take into consideration potential conflicting Russian interests in the market for natural gas in Europe and the market for emission permits under the Kyoto Protocol. The present analysis is a follow up to Holtsmark and Mæstad (2002), which found that an increasing permit price is likely to cause fuel switching from gas to oil in the European market. This is related to the fact that in Western Europe end user taxes on oil products are on average higher than end-user taxes on gas. It is assumed that the current structure of fiscal fossil fuel taxation in Western Europe is sustained into the first commitment period of the Kyoto Protocol. Hence, as a permit price is added to the end-user prices, the relative increase in the average consumer price of oil relative to gas is smaller than implied by the underlying emission factors. Consequently, the introduction of a permit market in Western Europe should cause substitution from gas to oil. As a large gas producer with considerable market power in Europe it should be in the interests of the Russian Federation to minimize this substitution in order to defend the gas price in Europe. Hence, the permit supply from the Russian Federation might turn out to be larger than a simpleminded monopolistic behavior should indicate.

The analysis has shown that the Clean Development Mechanism (CDM) will be important for Russian choice of strategy in the permit market. The permit supply from this mechanism will reduce considerably the market power of Russia and FSU because this mechanism is likely to represent an elastic supply of permits on the market. This will cause a low permit price. The drop in the permit price caused by CDM will alter the strategic behavior of FSU because the gas market is then much less influenced by the permit market. Hence, as CDM is included in the analysis the permit supply from FSU is only slightly higher in the case where FSU has a coordinated strategic behavior in the permit and gas market.

The paper provides a number of model simulations based on different assumptions with respect to baseline emissions and demand elasticities in the fossil fuel markets. Although the permit price is below 10 USD/tonnes CO_2 given that CDM is taken into consideration, the diverging results illustrate how difficult it is to provide estimates of the permit price and consequently the costs of the Kyoto Protocol only five years ahead of the first commitment period. It is still difficult to predict to what extent the Kyoto Protocol will give rise to significant emission reductions and what will be the price level in the permit market, if the Protocol finally enters into force.

After the U.S. and Australian withdrawal the environmental output will nevertheless be relatively small. Even in the High Growth scenario the global emission reduction is only slightly above 2 percent of global emissions also when FSU acts as a cartel in the permit market and restricts the permit export.

Concerning the permit price, the presented estimates vary from zero to 14.6 USD/ tonnes, if the baseline price elasticities are applied. After all it is reasonable to emphasize the cases that include CDM and where FSU acts strategically in the permit market. That means that we should rely on the results of case 3 and/or 4. Regardless of choice of BAU-scenario the permit price estimates is then within the range of 2.4 to 5.0 USD/AAU, if the baseline price-elasticities are applied. If we include the simulations using doubled and halved price-elasticities, the permit prices are in the range 1.3 to 9.5 USD/tonnes CO_2.

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The model

The model is a static partial-equilibrium model of global CO_2-emissions from combustion of fossil fuels. There are five markets for fossil fuels; one global coal market, one global oil market, and three regional gas markets (North America, Asia, and Europe including the Russian Federation). High transportation costs for natural gas are the usual reason why it is appropriate to regionalize the gas market. In an analysis of the Kyoto Protocol and the emerging permit market it is important to define regional gas markets also in order to take care of the interactions between the fossil fuel markets and the permit market, especially how carbon leakage is different in global and regional fossil fuel markets.

The model incorporates an international market for emission permits among the Annex B countries. The model determines endogenously equilibrium prices in the fuel markets, the quantities of fossil fuels produced and consumed in each country/region and consequently the trade movements, each country/region's import or export of emission permits, and the international price of emission permits. It is assumed that the countries with emission caps add at carbon tax equal to the price of emission permits on top of existing end-user taxes. This could, however, also be interpreted as if the countries establishes domestic permit markets which are fully integrated into the international permit market.

The national/regional economies are modeled in a simple frameworks: In each country/region a numeraire good is produced using three inputs; oil (1), coal (2), natural gas (3). In addition to the producer price of the fuels, the producer of the numeraire good pay fiscal taxes and emission permits (carbon taxes). From profit-maximizing behavior follows the demand functions for fossil fuels. The fossil fuels demand functions are interrelated through cross-price effects. The assumed production technology yields linear demand function for all inputs. Let P_{in} denote the end-user price in country n of input i ($i = 1,2,3$). Demand functions in country n can then be written as:

$$D_{in}(P_{jn}) = a_{in} + \sum_{j=1}^{3} a_{ijn} P_{jn}, \quad i = 1,2,3, \qquad \text{(A.1)}$$

where $a_i > 0$ and $a_{ij} < (>)\ 0$ for $i = j\ (i \neq j)$.

Let *N*, *E*, and *A* denote the set of countries located in North-America, Europe and Asia, respectively. The consumer price of input i in country n, located in region *r*, is the sum of the (regional) producer price (p_{ir}), a national excise tax (t_{in}), and the emission factor of input i (e_i) times the price of emission permits in the permit market (p_C):

$$P_{in} = p_{ir} + t_{in} + e_i p_C, \quad n \in r, \; r = N, A, E \,. \tag{A.2}$$

Note that it is only in the gas market that producer prices differ between regions.

The oil market and the European gas market are modeled with a dominant 'firm' (OPEC and FSU respectively) and price taking fringes. The coal market and the two other regional gas markets are assumed to be competitive. The assumed production technology of the price takers in all five fossil fuel markets yields linear supply functions:

$$S_{in}\,(p_i) = s_{in} + b_{in}p_i, \quad n \neq OPEC,\ FSU. \tag{A.3}$$

where s_{in} and b_{in} are parameters ($b_{in} \geq 0$).

Let x_{in} denote the quantity of fuel i produced in country n. Let c_{OPEC1} denote the constant marginal (unit) costs of oil-production in OPEC and c_{FSU3} the (constant) marginal costs of gas-production in FSU. As a dominant firm OPEC solves the problem:

$$\max_{x_{1OPEC}} \left\{ (p_1 - c_{OPEC}) x_{1OPEC} \right\}$$
$$s.t.\ x_{1OPEC} = \sum_n D_{1n}(p_1, p_2, p_{3A}) - \sum_{n \neq OPEC} S_{1n}(p_1)$$

Correspondingly FSU solves the problem:

$$\max_{x_{3FSU}} \left\{ p_{3E} x_{3FSU} - c_{FSU} x_{3FSU} \right\}$$
$$s.t.\ x_{3FSU} = \sum_{n \in E} D_{3n}(p_1, p_2, p_{3E}) - \sum_{n \in E \neq FSU} S_{3n}(p_{3E})$$

The first order conditions follows;

$$\frac{dp_1}{dx_{1OPEC}} x_{1OPEC} + p_1 = c_{OPEC3} \,. \tag{A.4}$$

$$\frac{dp_{3E}}{dx_{3FSU}} x_{3FSU} + p_{3E} = c_{FSU3} \,. \tag{A.5}$$

In the Kyoto Protocol, each of the Annex B countries is assigned an emission quota of GHGs, an Assigned Amount. Let E_n and Q_n denote the total emissions and the Assigned Amount for country *n* respectively. Since the emission factors are constants, we will measure all variables in terms of CO_2-emissions, which means that $e_i = 1$, $i = 1,2$, and 3. We can then write $E_n = \sum_{i=1}^{3} y_{in}$.

It is reasonable to assume that some large countries, not least Russia, might want to act strategically in the international market for emission permits. In some of the model simulations presented in this paper it is assumed that FSU acts as a cartel and maximizes its net income from permit sales after substraction of abatement costs, if any.

We define X_n and Π_n as country *n*'s permit export and profit in the permit market, respectively. We have:

$\Pi_{FSU} = p_C X_{FSU} - a_{FSU}(E_{BAU,FSU} - E_{FSU})$

where $E_{BAU,FSU}$ is the FSU-emissions in the BAU-scenario, while a_{FSU} is marginal abatement costs. If FSU sells hot air only there are no abatement costs, and $X_{FSU} < Q_{FSU} - E_{FSU}$ and the above equation is reduced to:

$\Pi_{FSU} = p_C X_{FSU}$

We then have the first order condition when FSU acts as a cartel in the permit market:

$$dq \frac{dq}{de_{FSU}} + p_C = \begin{cases} 0 \ \ if\ e_{FSU} < Q_{FSU} - E_{BAU,FSU} \\ \quad a_{FSU}\ otherwise. \end{cases} \tag{A.6}$$

The model determines the vector ($p_1, p_2, p_{3N}, p_{3A}, p_{3E}, p_C, x_{OPEC1}, x_{FSU3}, X_{FSU}$) from equation (A.4), (A.5), and (A.6) as well as the following six equilibrium conditions:

Equilibrium in the oil and coal markets:

$$\sum_n x_{in} = \sum_n y_{in}, \quad i = 1,2 . \tag{A.7}$$

Equilibrium in the three regional gas markets:

$$\sum_{n \in r} x_{3n} = \sum_{n \in r} y_{3n}, \quad r = N, A, E . \tag{A.8}$$

Equilibrium in the permit market:

$$\sum_{n} E_n = \sum_{n} Q_n . \tag{A.9}$$

Data, calibration and further simulation results

The starting point of a numerical analysis of consequences of the Kyoto Protocol should be one or more BAU-scenarios for the first commitment period (2008-12). In this paper the BAU-scenarios are based on the three scenarios for 2010 in the Internationial Energy Outlook 2002 (DOE) from U.S. Department of Energy. 2010 is chosen as a representive year for the first commitment period. Consumption and production of fossil fuels in the three scenarios are presented in table B.1-B.3. Million metric tonnes CO_2 is chosen as unit. One ton CO_2 is equal to 3.66 tonnes carbon. Otherwise the conversion factors used in DOE (2002) are applied.

Table B.1. Production and consumption of fossil fuels in 2010 in the Reference scenario. (Measured in corresponding million metric tonnes CO_2)

	Production			Consumption		
	Oil	Coal	Gas	Oil	Coal	Gas
U.S.	1189	2637	1224	2827	2383	1514
Canada	428	165	484	286	154	194
Western Europe	428	206	667	2041	687	1055
Norway	535	0	143	34	2	12
Former Soviet Union	1617	533	1093	638	517	821
Eastern Europe*	40	493	30	257	378	220
Algeria	267	0	240	26	1	65
OPEC	5359	0	0	731	53	509
Other developing countries	2820	4720	40	4985	4987	1886
Japan	0	4	28	752	345	158
Australia	107	952	2555	213	202	70
World	12789	9709	6505	12789	9709	6505

* Bulgaria, Croatia, Czech Republic, Hungary, Poland, Romania, Slovakia, and Slovenia.

The consumption data in table B.1 are taken almost directly from DOE 2002. However, DOE does not supply data on Norway and Algeria, which are included in order to give a realistic model of the European gas market. Norwegian data on both consumption and production are taken from official Norwegian planning documents. Fossil fuel consumption in Algeria in 2010 is in all three scenarios based on a continuation of the consumption and production growth in this country from 1990 to 2000.

Construction of the oil production data in the Reference scenario is based on table D1 in DOE 2002. DOE does, however, not provide data on regionalized production data of coal and natural gas in 2010. These data are therefore constructed based on extension of the different regions production growth from 1990 to 2000. In order to have equality between production and consumption in the three regional gas markets and the coal market, the regions estimated production in 2010 are finally adjusted by the same rate. This method is also applied in construction of the regionalized production of coal and natural gas in the High and Low Growth Scenarios, cf. Table B.2 and B.3.

Table B. 2. Production and consumption of fossil fuels in 2010 in the High Growth scenario. (Measured in corresponding million metric tonnes CO_2)

	Production			Consumption		
	Oil	Coal	Gas	Oil	Coal	Gas
U.S.	1317	2877	1269	2930	2424	1566
Canada	474	180	502	304	161	205
Western Europe	474	225	713	2136	724	1110
Norway	592	0	153	34	2	12
Former Soviet Union	1791	582	1167	696	565	896
Eastern Europe	44	538	32	275	403	238
Algeria	296	0	257	26	1	65
OPEC	5935	0	0	863	61	601
Other developing countries	3123	5149	47	5888	5680	2229
Japan	0	4	33	788	363	165
Australia	118	1038	2989	224	209	73
World	14164	10593	7161	14164	10593	7161

Table B. 3. Production and consumption of fossil fuels in 2010 in the Low Growth scenario. (Measured in corresponding million metric tonnes CO_2)

	Production			Consumption		
	Oil	Coal	Gas	Oil	Coal	Gas
U.S.	1111	2382	1187	2765	2343	1474
Canada	399	149	470	271	143	183
Western Europe	399	187	620	1942	658	1004
Norway	499	0	133	34	2	12
Former Soviet Union	1510	482	1016	572	466	739
Eastern Europe	37	445	28	235	345	202
Algeria	250	0	224	26	1	65
OPEC	5004	0	0	667	46	*467*
Other developing countries	2633	4264	37	4547	4265	1732
Japan	0	3	26	686	315	143
Australia	100	860	2345	198	187	66
World	11942	8771	6087	11942	8771	6087

The oil price is set to 26 USD/barrel in all the three BAU-scenarios. This corresponds to 190 USD/ metric tonnes oil equivalent (toe) and 70 USD/tonnes CO_2. The producer price in the coal market is assumed to be 55.6 USD/toe. In the three regional gas markets the BAU-prices 4.3 USD/mill. British termal units (MBtu) in North-America, 4.4 USD/MBtu in Europe and 5.2 USD/MBtu in the Pacific region. This corresponds to 80.3, 82.3, and 97.1 USD/tonnes CO_2 in the three markets, respectively.

Consumer prices in the BAU scenario are obtained by adding fiscal taxes to the producer prices. The tax rates are from ECON (1995), which is mainly based on the IEA data base on energy prices and taxes, (IEA, 1995), cf. table B.4.

Table B. 4. Assumed fiscal taxes on fossil fuel consumption. (USD/tonnes CO_2)

	Oil	Coal	Gas
U.S.	18	0	0
Canada	35	0	0
Western Europe	73	1	12
Norway	50	24	0
Former Soviet Union	0	-1	-1
Eastern Europe	0	0	-1
Algeria	-	-	-
OPEC	-	-	-
Other developing countries	-	-	-
Japan	33	0	0
Australia	42	0	0

The demand functions have been calibrated by imposing a measure of the price elasticity of demand for each fuel in each country. The chosen demand elasticities are presented in table 1. There is no consensus in the literature about price elasticities in fossil fuel markets. Estimates range from –0.15 to about –1.0 (e.g., Smith *et al.* (1995), Brubakk *et al.* (1995)). In lack of decisive evidence, a middle road is chosen by assuming that the average price elasticity of demand is –0.5 for all fossil fuels.

As in Holtsmark and Mæstad (2002) the own-price elasticities of oil, coal and gas demand have been differentiated across countries in order to reflect the different structure of fuel demand in various countries. The method is further described in Holtsmark and Mæstad (2002).

Estimates of cross-price elasticities also vary significantly in the literature. Brubakk *et al.* (1995) find long-run elasticities between 0.01 and 0.5 (average about 0.1). As a certain pattern is difficult to see, I have followed Holtsmark and Mæstad (2002) and chosen 0.1 as the average cross-price elasticity between all fossil fuels in all countries. Any deviations from the average are due to the restriction that cross-price derivatives of factor demand functions should be symmetric (i.e. $a_{ij} = a_{ji}$).[6]

As for fuel supply, it is generally recognized that the supply of coal is more elastic than the supply of other fuels. We have followed Golombek *et al.* (1995) by assuming supply elasticities of 2.0 for coal producers and 1.0 for competitive gas and oil producers.

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[6] Let ε_{ij} denote the cross-price elasticity between fuels i and j. Then, $\varepsilon_{ij} \equiv a_{ij} P_j \big/ y_i = a_{ji} P_j \big/ y_i$, which implies the following relationship between the cross-price elasticities; $\varepsilon_{ij} = \varepsilon_{ji} P_j y_j \big/ P_i y_i$.

Tables

Table C.5. Fossil fuel producer prices. Percentage change from baseline

	Case				
Low growth scenario	1	2	3	4	5
Oil	0.00	-0.30	-0.34	-0.12	-0.31
Coal	0.00	-0.96	-0.94	-0.36	-0.88
Natural gas in North America	0.00	-0.18	-0.11	-0.07	-0.11
Natural gas in Europe	0.00	-0.46	-0.20	-0.43	-0.19
Natural gas in the Pacific region	0.00	-0.05	-0.49	-0.02	-0.46
Reference scenario					
Oil	0.00	-0.49	-0.53	-0.30	-0.51
Coal	0.00	-1.52	-1.52	-0.93	-1.46
Natural gas in North America	0.00	-0.30	-0.18	-0.18	-0.17
Natural gas in Europe	0.00	-0.74	-0.31	-0.59	-0.29
Natural gas in the Pacific region	0.00	-0.06	-0.74	-0.04	-0.71
High growth scenario					
Oil	-0.44	-0.60	-0.67	-0.42	-0.65
Coal	-1.33	-1.92	-1.90	-1.33	-1.85
Natural gas in North America	-0.22	-0.39	-0.23	-0.27	-0.22
Natural gas in Europe	-1.77	-0.95	-0.38	-0.71	-0.36
Natural gas in the Pacific region	-0.06	-0.08	-0.95	-0.06	-0.92

Table C.6. End-user prices in the Reference scenario. Percentage change from baseline

Oil					
Case	1	2	3	4	5
USA	0.00	-0.39	-0.42	-0.24	-0.40
Canada	0.00	10.27	3.42	6.26	3.29
Western Europe	0.00	7.60	2.53	4.63	2.44
Eastern Europe	0.00	3.89	1.07	2.41	1.03
FSU	0.00	-0.49	-0.53	-0.30	-0.51
Japan	0.00	10.51	3.50	6.40	3.37
Coal					
Case	1	2	3	4	5
USA	0.00	-0.96	-0.94	-0.36	-0.88
Canada	0.00	30.54	10.91	11.52	10.24
Western Europe	0.00	29.21	10.43	11.02	9.79
Eastern Europe	0.00	11.40	4.00	4.61	3.77
FSU	0.00	-0.99	-0.97	-0.38	-0.91
Japan	0.00	30.54	10.91	11.52	10.24
Gas					
Case	1	2	3	4	5
USA	0.00	-0.39	-0.42	-0.24	-0.40
Canada	0.00	10.27	3.42	6.26	3.29
Western Europe	0.00	7.60	2.53	4.63	2.44
Eastern Europe	0.00	2.10	0.44	1.32	0.42
FSU	0.00	-0.49	-0.53	-0.30	-0.51
Japan	0.00	10.51	3.50	6.40	3.37

Table C.7. End-user prices in the High growth scenario. Percentage change from baseline

Oil					
Case	1	2	3	4	5
USA	-0.35	-0.48	-0.53	-0.33	-0.51
Canada	6.71	13.38	4.23	9.25	4.11
Western Europe	4.97	9.91	3.13	6.84	3.05
Eastern Europe	10.03	4.95	1.28	3.48	1.25
FSU	10.03	-0.60	-0.67	-0.42	-0.65
Japan	6.86	13.69	4.33	9.46	4.21
Coal					
Case	1	2	3	4	5
USA	-1.33	-1.92	-1.90	-1.33	-1.85
Canada	32.82	65.27	20.90	45.10	20.32
Western Europe	31.40	62.47	19.99	43.15	19.44
Eastern Europe	33.67	20.34	7.08	15.51	6.91
FSU	33.99	-1.99	-1.97	-1.37	-1.91
Japan	32.82	65.27	20.90	45.10	20.32
Gas					
Case	1	2	3	4	5
USA	-0.35	-0.48	-0.53	-0.33	-0.51
Canada	6.71	13.38	4.23	9.25	4.11
Western Europe	4.96	9.90	3.13	6.84	3.04
Eastern Europe	10.03	2.67	0.51	1.91	0.50
FSU	10.03	-0.60	-0.67	-0.42	-0.65
Japan	6.86	13.69	4.33	9.46	4.21

Table C.8. End-user prices in the Low growth scenario. Percentage change from baseline

Oil					
Case	1	2	3	4	5
USA	0.00	-0.24	-0.27	-0.09	-0.25
Canada	0.00	6.26	2.21	2.36	2.07
Western Europe	0.00	4.64	1.63	1.75	1.53
Eastern Europe	0.00	2.45	0.71	0.94	0.67
FSU	0.00	-0.30	-0.34	-0.12	-0.31
Japan	0.00	6.40	2.26	2.42	2.12
Coal					
Case	1	2	3	4	5
USA	0.00	-0.96	-0.94	-0.36	-0.88
Canada	0.00	30.54	10.91	11.52	10.24
Western Europe	0.00	29.21	10.43	11.02	9.79
Eastern Europe	0.00	11.40	4.00	4.61	3.77
FSU	0.00	-0.99	-0.97	-0.38	-0.91
Japan	0.00	30.54	10.91	11.52	10.24
Gas					
Case	1	2	3	4	5
USA	0.00	-0.24	-0.27	-0.09	-0.25
Canada	0.00	6.26	2.21	2.36	2.07
Western Europe	0.00	4.63	1.63	1.75	1.53
Eastern Europe	0.00	1.35	0.30	0.52	0.28
FSU	0.00	-0.30	-0.34	-0.12	-0.31
Japan	0.00	6.40	2.26	2.42	2.12

Table C.9. Fossil fuel consumption in the Reference scenario. Percentage change from baseline

Oil					
Case	1	2	3	4	5
USA	0.0	0.1	0.1	0.0	0.1
Canada	0.0	-2.9	-1.0	-1.8	-0.9
Western Europe	0.0	-2.5	-0.8	-1.5	-0.8
Eastern Europe	0.0	-1.3	-0.3	-0.8	-0.3
FSU	0.0	0.2	0.3	0.1	0.3
Japan	0.0	-5.5	-1.8	-3.3	-1.8
Rest of the world	0.0	0.1	-1.5	0.1	-1.4
Annex B	0.0	-1.0	-1.4	-0.6	-1.3
World	0.0	-0.8	-0.9	-0.5	-0.8
Coal					
Case	1	2	3	4	5
USA	0.0	0.9	0.9	0.5	0.9
Canada	0.0	-26.0	-8.7	-15.8	-8.4
Western Europe	0.0	-23.0	-7.7	-14.0	-7.4
Eastern Europe	0.0	-9.9	-3.0	-6.0	-2.9
FSU	0.0	0.6	0.7	0.3	0.7
Japan	0.0	-14.2	-4.9	-8.7	-4.7
Rest of the world	0.0	0.4	-4.4	0.2	-4.3
Annex B	0.0	-1.3	-3.9	-0.8	-3.7
World	0.0	-3.0	-3.0	-1.9	-2.9
Gas					
Case	1	2	3	4	5
USA	0.0	0.0	-0.1	0.0	-0.1
Canada	0.0	-2.3	-0.9	-1.4	-0.8
Western Europe	0.0	-1.8	-0.7	-1.0	-0.6
Eastern Europe	0.0	-0.8	-0.3	-0.4	-0.3
FSU	0.0	0.6	0.2	0.5	0.2
Japan	0.0	0.3	0.3	0.2	0.3
Rest of the world	0.0	-0.6	-1.7	-0.5	-1.6
Annex B	0.0	-0.1	-0.7	0.0	-0.7
World	0.0	-0.5	-0.5	-0.3	-0.5

Table C.10. Fossil fuel consumption in the High growth scenario. Percentage change from baseline

Oil					
Case	1	2	3	4	5
USA	0.0	0.1	0.1	0.0	0.1
Canada	0.0	-2.9	-1.0	-1.8	-0.9
Western Europe	0.0	-2.5	-0.8	-1.5	-0.8
Eastern Europe	0.0	-1.3	-0.3	-0.8	-0.3
FSU	0.0	0.2	0.3	0.1	0.3
Japan	0.0	-5.5	-1.8	-3.3	-1.8
Rest of the world	0.0	0.1	-1.5	0.1	-1.4
Annex B	0.0	-1.0	-1.4	-0.6	-1.3
World	0.0	-0.8	-0.9	-0.5	-0.8
Coal					
Case	1	2	3	4	5
USA	0.8	1.1	1.1	0.8	1.1
Canada	-17.0	-33.8	-10.8	-23.4	-10.5
Western Europe	-15.2	-29.9	-9.6	-20.7	-9.3
Eastern Europe	-15.4	-12.7	-3.7	-8.8	-3.6
FSU	-14.9	0.8	0.9	0.5	0.8
Japan	-9.3	-18.5	-6.0	-12.8	-5.9
Rest of the world	1.9	0.4	-5.4	0.3	-5.2
Annex B	-0.7	-1.5	-4.7	-1.1	-4.6
World	-2.7	-3.8	-3.8	-2.7	-3.7
Gas					
Case	1	2	3	4	5
USA	0.0	0.0	-0.1	0.0	-0.1
Canada	0.0	-2.3	-0.9	-1.4	-0.8
Western Europe	0.0	-1.8	-0.7	-1.0	-0.6
Eastern Europe	0.0	-0.8	-0.3	-0.4	-0.3
FSU	0.0	0.6	0.2	0.5	0.2
Japan	0.0	0.3	0.3	0.2	0.3
Rest of the world	0.0	-0.6	-1.7	-0.5	-1.6
Annex B	0.0	-0.1	-0.7	0.0	-0.7
World	0.0	-0.5	-0.5	-0.3	-0.5

Table C.11. Fossil fuel consumption in the Low growth scenario. Percentage change from baseline

Oil					
Case	1	2	3	4	5
USA	0.0	0.0	0.0	0.0	0.0
Canada	0.0	-1.8	-0.6	-0.7	-0.6
Western Europe	0.0	-1.5	-0.5	-0.6	-0.5
Eastern Europe	0.0	-0.8	-0.2	-0.3	-0.2
FSU	0.0	0.1	0.2	0.0	0.2
Japan	0.0	-3.3	-1.2	-1.3	-1.1
Rest of the world	0.0	0.1	-1.0	0.0	-0.9
Annex B	0.0	-0.6	-0.9	-0.2	-0.8
World	0.0	-0.5	-0.5	-0.2	-0.5
Coal					
Case	1	2	3	4	5
USA	0.0	0.6	0.6	0.2	0.5
Canada	0.0	-15.8	-5.6	-6.0	-5.3
Western Europe	0.0	-14.0	-5.0	-5.3	-4.7
Eastern Europe	0.0	-6.1	-2.0	-2.3	-1.9
FSU	0.0	0.4	0.4	0.1	0.4
Japan	0.0	-8.7	-3.2	-3.3	-3.0
Rest of the world	0.0	0.2	-2.8	0.1	-2.6
Annex B	0.0	-0.8	-2.4	-0.3	-2.3
World	0.0	-1.9	-1.9	-0.7	-1.8
Gas					
Case	1	2	3	4	5
USA	0.0	0.0	-0.1	0.0	-0.1
Canada	0.0	-1.4	-0.6	-0.5	-0.5
Western Europe	0.0	-1.1	-0.4	-0.3	-0.4
Eastern Europe	0.0	-0.5	-0.2	0.0	-0.2
FSU	0.0	0.4	0.1	0.4	0.1
Japan	0.0	0.2	0.2	0.1	0.2
Rest of the world	0.0	-0.4	-1.1	-0.3	-1.0
Annex B	0.0	0.0	-0.5	0.0	-0.4
World	0.0	-0.3	-0.3	-0.1	-0.3

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