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UNILATERAL EMISSION PRICING AND OPEC'S BEHAVIOUR

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Abstract

Unilateral climate policies involve the risk of carbon leakage, driven by price changes in the oil market and other international markets. We have shown in previous analysis that OPEC may have an incentive to increase the oil price as a response to EU climate policy, thereby retaining resource rents and turning leakage through the oil market negative. In this paper, we examine the implications of OPEC's strategic responses more thoroughly by extending our former analysis along four key dimensions: (i) the size of the climate coalition, (ii) the size of the oil cartel, (iii) oil-gas price linkages in the EU and Japan, and (iv) subsidies for oil consumption within OPEC. We show that the coalition or cartel size critically affect the scope for rent seeking and leakage reduction, whereas oil-gas price linkages in the EU and Japan or subsidies within OPEC do not alter the findings of our previous analysis.

Keywords: Carbon Leakage, Oil Market, OPEC Behaviour

JEL: C72; Q41; Q54

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1. Introduction

A major drawback associated with unilateral climate policies is the risk of carbon leakage: price changes in international markets for fossil fuels and energy-intensive goods might lead to the relocation of emissions from countries with emission regulation to unregulated regions. Obviously, carbon leakage hampers the cost-effectiveness of unilateral action. Branger and Quirion (2014) provide a comprehensive overview and meta-analysis of the applied literature on unilateral climate policy and carbon leakage. One common finding is that carbon leakage to a large extent takes place through price changes on international energy markets. However, most previous studies assume international energy market to be perfectly competitive, thus disregarding empirical evidence on non-competitive behaviour of members of the Organization of Petroleum Exporting Countries (OPEC) in the crude oil market (see literature below).

As shown in Böhringer, Rosendahl and Schneider (2014), the assumption of imperfect competition in the international crude oil market may substantially affect outcomes with respect to carbon leakage as well as global and regional cost implications of unilateral climate policies. A computable general equilibrium (CGE) model is used to assess two different climate policy scenarios for the EU, with five alternative assumptions about OPEC's strategic response. As to EU climate policy design, the EU unilaterally implements a cap on global emissions. As to behavioural assumption on OPEC, OPEC can either act competitively; or ration its crude oil supply in order to hold the crude oil price, or crude oil revenues, or its supply quantity fixed; or act as a dominant producer maximizing its crude oil profits. The main finding is that if OPEC acts as a dominant producer, the oil price increases when the EU introduces its climate policy. This is due to OPEC's incentive to shift over climate rents from emission pricing: since the EU pursues a global emissions target, OPEC can drive down EU's CO_2 price via an increased oil price. As the oil price increases, non-EU demand declines and hence leakage through the oil market turns negative. However, global cost-effectiveness of unilateral emission reduction is seriously deteriorated under the assumption of imperfect competition because too much of the mitigation takes place through reduction in oil consumption.

In this paper, we elaborate on the analysis in Böhringer, Rosendahl and Schneider (2014). More specifically, we test the robustness of the conclusions to variations in four potentially critical assumptions: (i) the size of the climate coalition, (ii) the size of the oil cartel, (iii) oil-gas price linkages in the EU and Japan, and (iv) subsidies to domestic oil consumption within OPEC. Our primary objective is to foster our understanding on how such variations affect the implicatctions of OPEC's strategic behaviour.

As to (i) – the size of the climate coalition – we take into account that countries outside the EU might also implement stringent carbon pricing or equivalent emission regulations.[1] In the context of the 21st Conference of Parties (COP21) to the United Framework Convention of Climate Change in Paris in December 2015, many countries

[1] As summarized in World Bank (2015), about 40 countries and more than 20 subnational jurisdictions are pricing CO_2 emissions as of 2015.

communicated their intended nationally determined contributions (INDCs) to reduce greenhouse gas (GHG) emissions (UNFCCC, 2015). The United States, for example, stated a target of reducing GHG emissions by 26–28% below 2005 levels by 2025, and has launched a clean power plan to reduce CO_2 emissions in the power sector in addition to existing policies such as fuel efficiency standards for cars. China as the major greenhouse gas emitter world-wide announced that it will establish a national emission trading system from 2017 onwards, preluded by seven pilot trading schemes at the provincial level (Zhang, 2015), to peak emissions around 2030. It remains to be seen how the voluntary INDCs of countries will be followed up in more detail over the next years, but for our analysis it seems reasonable to enlarge the climate policy size beyond the EU by additional members such as the US, other remaining OECD countries, or China.

As to (ii) – the size of the oil cartel – one string of literature treats OPEC as a whole acting as a dominant producer or price leader (e.g., Böckem, 2004). Another string finds dominant behaviour only for OPEC-core (e.g., Hansen and Lindholt, 2008) – consisting of Saudi Arabia, Kuwait, Qatar, and the United Arab Emirates – or only Saudi Arabia (e.g., Alhajji and Huettner, 2000a). For strategic responses to unilateral climate policies, the market share of the cartel plays a major role as a determinant of actual market power. To account for different perspectives on OPEC members' roles in the oil market, we vary the cartel size and incorporate scenarios where only OPEC-core or only Saudi Arabia instead of OPEC as a whole acts strategically.

As to (iii) – oil-gas price linkages in the EU and Japan – price responses to emission regulation across fossil fuels drive fuel switching, and thus the scope for emission abatement via reductions in the CO_2 intensity of energy use. Fuel switching from coal to gas in electricity generation is thereby considered to be of particular importance for cost-effective CO_2 emssion reduction (Delarue and D'haeseleer, 2008). However, gas import prices in the EU and in the Asia-Pacific region are closely linked to the international crude oil price. In continental Europe natural gas import prices have traditionally been determined through long-term contracts related to oil products including an annual contract quantity with a minimum take-or-pay level (European Commission, 2007). Although there is an increasing tendency towards competitive pricing along the installation of gas hubs and augmented spot-priced liquefied natural gas (LNG) supplies over recent years (Stern and Rogers, 2014) – import prices are still strongly determined by oil-indexed contracts, particularly in central and southern Europe. Without domestic gas resources and transnational pipeline connections, Japan is by far the world's largest importer of LNG. For the past 25 years Japan's LNG import prices have been closely linked to international crude oil prices through the so-called "Japanese Customs-Cleared Crude Oil" (JCC) index (Rogers and Stern, 2014). Against this background, we investigate the sensitivity of initial conclusions in Böhringer, Rosendahl and Schneider (2014) when accounting for price linkages between the international crude oil price and the import price for natural gas in the EU and Japan.

As to (iv) – subsidies to domestic oil consumption within OPEC – we acknowledge that fossil fuel consumption is highly subsidized in many countries, incentivizing demand and distorting allocative efficiency of resource allocations. In 2011, the IEA (2012) estimated total fossil fuel subsidies to be 523 billion USD, with oil subsidies of 285 billion

USD constituting the major part. OPEC members stand out for very high subsidies to domestic oil consumption, with Iran and Saudi Arabia accounting for almost 90 billion USD.[2] We reflect the policy practise of domestic oil subsidies in OPEC countries, which implies that OPEC countries do not exploit market power on their domestic markets.

Our simulation results on variations of key assumptions (i) – (iv) suggest that negative leakage through the oil market as identified in Böhringer, Rosendahl and Schneider (2014) cannot be generalized and constitutes a rather special outcome. The implications of strategic responses by OPEC to unilateral emission pricing hinge in particular on the size of the climate coalition and the size of the oil cartel. As a prime example, OPEC's ability to lower the coalition's CO_2 price is reduced markedly when China is part of the coalition. The reasoning is that China brings plenty of low-cost coal-related abatement options into the coalition which implicitly lowers OPEC's incentives to cut back supply. When only OPEC-core or Saudi Arabia act dominantly instead of OPEC as a whole, the results resemble the outcome of a competitive market setting: the cartels' market share is no longer sufficiently large to noticeably impact on the EU's CO_2 price. A price linkage between the crude oil price and gas import prices gives opposing incentives to OPEC when assuming dominant behavior, which in total leads to a market outcome which is similar to the case without the price link, except for declining gas imports in Europe and Japan. Assuming existing subsidies to domestic consumers within OPEC does not significantly change OPEC's supply decision when facing an EU climate policy, only OPEC's crude oil consumption share is slightly higher than without subsidies.

The remainder of this paper is organized as follows. In Section 2, we briefly review some previous and relevant literature. Then in Section 3 we provide a non-technical description of the CGE model and empirical data underlying our simulation analysis. In Section 4, we present base-year statistics to identify key drivers of the counterfactual simulation results, while in Section 5 we lay out policy scenarios and discuss in detail our simulation results. Then Section 6 contains our conclusions.

2. Literature review

Our paper relates to different strands of literature. First, there is a number of studies analyzing strategic behavior in energy markets, including studies of the game between OPEC and climate coalitions, see for example Wirl (1994, 1995), Tahvonen (1995, 1996), Bråten and Golombek (1998), Rubio and Escriche (2001) and Liski and Tahvonen (2004). These studies focus on oil resource rents, and how a climate coalition may capture some of this rent by imposing emission constraints. Dullieux et al. (2011) introduce a carbon stock constraint imposed by oil-importing countries, and study the Markov-perfect Nash equilibrium of a dynamic game between these countries and oil-

[2] IEA (2012) calculates the value of subsidies that reduce end-user prices below those that would prevail in an open and competitive market. Alyousef & Stevens (2011) criticize the way the IEA calculates these subsidy volumes in Saudi Arabia. They make the point that the opportunity cost of domestic consumption cannot be the border price since Saudi Arabia is a price maker, but instead the correct reference price for domestic subsidy calculations is the long run marginal cost of production. Furthermore, Wie et al. (2012) conclude that climate policies in fuel consuming countries make it optimal for OPEC to increase subsidies to domestic oil consumers.

exporting countries. Their main finding is that the oil exporters are only able to shift rents if the marginal environmental damages below the stock constraint are sufficiently small. Wirl (2012) compares strategic price and quantity instruments for both the cartel and the climate coalition, concluding that price instruments dominate quantity instruments for both the cartel and the coalition. A similar conclusion is found by Strand (2013) for a climate coalition, which also has access to an offset market (such as CDM). A price instrument (emission tax) is preferred over a quantity instrument (emission cap) since the global fuel price is lower with the price instrument which is more effective in curtailing the strategic scope for the fuel exporter.

Kverndokk and Rosendahl (2013) show that fuel efficiency improvements in a climate coalition will lead to higher fuel prices if the dominant producer's market share is sufficiently large. Haurie and Vielle (2010) show that it is optimal for OPEC as a dominant producer to lose market share in order to keep the oil price from falling too much.

Our paper also relates to literature on the green paradox, initiated by Sinn (2008) and reviewed in e.g. Jensen et al (2015). The main message from this literature is that climate policies could lead to increased emissions of CO_2, as owners of fossil fuel resources may find it profitable to shift extraction of their non-renewable resources from the future to the present. This effect may be particularly strong if CO_2 prices are expected to increase over time.[3] Studies of the green paradox obviously require a dynamic model building on the non-renewable resource theory established by Hotelling (1931). In this vein, Gerlagh and Liski (2011) use a dynamic model of non-renewable resources to look into strategic behaviour by a monopolist owning a non-renewable resource (using oil as the motivating example), who faces competition from a new substitute.[4]

For our analysis, we assume that OPEC or a subgroup of OPEC acts as a dominant producer in the oil market. Thus, our findings rest on this assumption being reasonable. There is limited consensus in the literature regarding OPEC's behavior, except that most studies reject the hypothesis of competitive behavior (see e.g. Alhajji and Huettner, 2000a; Böckem, 2004; Smith, 2005; Hansen and Lindholt, 2008; Kaufmann et al., 2008; Huntington et al., 2013). Most studies consider the dominant producer model, and some empirical support has been found for either OPEC as a whole (e.g., Böckem, 2004; Golombek et al, 2014), or OPEC-core (e.g., Hansen and Lindholt, 2008), or only Saudi Arabia (e.g., Alhajji and Huettner, 2000a) acting as the dominant producer. Some numerical models have assumed Cournot behavior (e.g., Salant, 1982; Berg et al., 2002; Okullo et al., 2015), whereas the target revenue hypothesis was tested by Alhajji and Huettner (2000b) for individual countries (not Saudi Arabia) with mixed conclusions. Smith (2005) considers a variety of models, finding that "all traditional explanations of OPEC behavior (i.e., competitive, Cournot, dominant-firm, etc.) are strongly rejected, except the hypothesis that OPEC acts as a bureaucratic syndicate", which he characterizes as "a cartel weighed down by the cost of forging and enforcing consensus among its members".

[3] Gerlagh (2010) distinguishes between a weak and a strong green paradox, where the former refers to cases where current emissions increase, whereas the latter refers to cases where even long term climate damages increase.

[4] The analysis presented in this paper is static and abstracts from dynamic effects. In the conclusions, we briefly discuss how our results could change when adopting a dynamic perspective.

3. Model and data

Our conceptual framework is based on the dominant producer model where the strategic element can be summarizedas follows (see the Appendix A for a brief formal description). First, the climate coalition announces its climate target, formulated as a cap on emissions, and decides to implement an economy-wide CO_2 price in order to reach this target. Since climate change is a global problem, we postulate that the climate coalition is concerned about global emissions, and consequently pursues a global emission reduction target through unilateral action. Next, whereas competitive producers in the fossil fuel markets adjust their supply according to the price of the fuel they sell, the dominant producer in the oil market (OPEC, OPEC-Core or Saudi Arabia) adjusts its production in order to maximize its profits from this market. In particular, the dominant producer realizes that its supply of oil does not only affect the price of oil, but also the price of CO_2 implemented by the coalition, which again has a feedback effect on the oil price through the demand for oil. Consequently, if the dominant producer decides to reduce its supply, more of the rent in the oil market will be shifted back to the dominant producer, partly due to a lower CO_2 price. This gives the producer more incentives to cut back on its supply compared to a situation where the climate coalition had instead imposed a fixed CO_2 price.

In order to quantify the magnitude of these mechansims, we use a canonical static computable general equilibrium (CGE) model of global trade and energy use. CGE models are widely used for the economic impact assessment of policy measures as they capture price-responsive supply and demand adjustments to external policy shocks in a comprehensive and consistent manner. Below we provide a brief non-technical description of our CGE model – a more elaborate description along with algebraic details can be found in Böhringer, Rosendahl and Schneider (2014). Parameterization of the model is based on the latest version of the *Global Trade Analysis Project* (GTAP 9) dataset (Narayanan, Aguiar and McDougall, 2015).

3.1. Non-technical model summary

Each model region has a representative agent that receives income from three primary factors: labour, capital, and fossil fuel resources. Labour and capital are intersectorally mobile within a region but immobile between regions; fossil fuel resources are specific to the fossil fuel production sectors coal, crude oil, and natural gas in each region.

Production and consumption activities are represented through multi-level nested constant elasticity of substitution (CES) functions, which capture price-responsive trade-offs between primary factors, energy inputs as well as intermediate material inputs. Fossil fuel production is calibrated to match exogenous estimates of fossil-fuel supply elasticities.[5]

[5] Graham, Thorpe and Hogan (1999); Krichene (2002); Ringlund, Rosendahl and Skjerpen (2008).

Final consumption in each region is determined by the representative agent who maximizes welfare subject to a budget constraint with fixed investment and exogenous government provision of public goods and services. A balance of payment constraint incorporates the base-year trade deficit or surplus for each region.

Crude oil is treated as a homogeneous commodity, i.e., all crude oil flows through a global market with one world-market price. For all other commodities, bilateral trade is specified following Armington's differentiated goods approach, where domestic and foreign goods are distinguished by origin (Armington, 1969).

CO_2 emissions are linked in fixed proportions to the use of coal, oil and gas, with CO_2 coefficients differentiated by fuels.

In order to introduce imperfect competition on the crude oil market, we calibrate the cost function within the respective cartel (OPEC, OPEC core, or Saudi Arabia) such that it is consistent with crude oil profit maximization in the base-year data. Across policy simulations, the respective cartel rations its crude oil supply in order to maximize profits.

3.2. Data

Our CGE simulation analysis builds on most recent data from the Global Trade Analysis Project (GTAP). Version 9 of the GTAP database includes national accounts on production and consumption, bilateral trade flows as well as fuel- and sector-specific CO_2 emissions for 140 regions and 57 sectors for the year 2011 (Narayanan, Aguiar and McDougall, 2015). We aggregate sectors and regions in the GTAP database towards a composite data set that reflects the specific requirements of our policy issue – see Table 1 for an overview of sectors and regions included in the model.

As to production sectors, our composite data set includes all major primary and secondary energy carriers: coal, crude oil, natural gas, refined oil products, and electricity. In addition, we separate the main emission-intensive and trade-exposed sectors: chemical products, non-metallic minerals, iron and steel products, and non-ferrous metals; these sectors are most affected from shifts in comparative advantage triggered by unilateral emission caps and are hence important to represent. As to regions, the composite dataset comprises twelve regions that are most relevant for our policy analysis, namely (i) countries and regions that adopt climate policies in one or more of our scenarios: Europe, the United States, remaining OECD, and China; (ii) regions that can exert market power in the crude oil market: Saudi Arabia, a composite region called remaining OPEC-core consisting of Qatar, Kuwait, and the United Arab Emirates, and remaining OPEC; and (iii) other countries and regions: Japan, India, Russia, other middle income countries, and other low income countries.

Table 1: Model sectors and regions

Sectors and commodities	Countries and regions
Energy	Europe – EU-28 plus EFTA
Coal	United States
Crude oil	Saudi Arabia
Natural gas	Remaining OPEC core*
Refined oil products	Remaining OPEC
Electricity	Remaining OECD
Emission-intensive & trade-exposed sectors	China
Chemical products	Japan
Non-metallic minerals	India
Iron and steel industry	Russia
Non-ferrous metals	Other middle income countries
Transport sectors	Other low income countries
Air transport	
Water transport	
Other transport	
Other industries and services	
All other manufactures and services	

**Qatar, Kuwait, United Arab Emirates*

To determine the free parameters of functional forms that characterize production technologies and consumer preferences, one requires a coherent observation of economic transactions for a particular base year: in our case GTAP 9 data for the base year 2011. Base-year data together with exogenous elasticity values calibrate the functional forms such that the GTAP dataset is consistent with market structure assumptions and optimizing behavior of economic agents.

4. Base-year statistics

We present base-year statistics to gain insights into important drivers of economic adjustment triggered by policy interference. In the context of our analysis, most relevant are fuel-specific emissions, crude oil supply and consumption patterns, as well as EU's and Japan's gas import dependency.

Fuel-specific emissions

The implications of emission regulation for international fuel markets and emission leakage is driven by the size and the composition of fossil fuels subjected to emission pricing. As more countries adopt a given percentage reduction in their base-year emissions, global energy demand drops further thereby inducing a stronger decline in international energy prices. While this leads to higher energy (emission) demands in non-regulated countries outside the climate coalition, the leakage rate shrinks with the coalition size since emission reduction in the enlarged coalition dominates (Böhringer, Fischer and Rosendahl, 2014). Beyond the size of the abatement coalition, oil market outcomes critically hinge on the amounts of fuel-specific emissions in the abatement coalition, because they determine how much of the mitigation takes places through reduced oil consumption: if countries with relatively few oil-related emissions decide to set a cap, the oil market will be less affected.

Figure 1 shows the amounts and percentage shares of coal-, gas-, and oil-related emissions in regions that are candidates for unilateral climate policies in our analysis. In terms of CO_2 emissions, the EU, the US, and remaining OECD rely heavily on oil: the oil-related emissions amount to a share of roughly 50% in the EU and remaining OECD, and over 40% in the US. China, however, exhibits only a share of 20% oil-related emissions, the remaining 80% are stemming from coal combustion. This fact already foreshadows that emission caps in coalitions of OECD countries shock the oil market more pronouncedly than coalitions including China. The amount of base-year emissions rises sharply with the coalition size from 4.1 Gt of CO_2 in the EU to 17.2 Gt of CO_2 for the coalition of OECD and China. The share of coal-related emissions jumps from around 30% for OECD countries to around 50% as soon as China joins the coalition, while at the same time the share of oil-related emissions drops from 45% - 50% to about 35%.

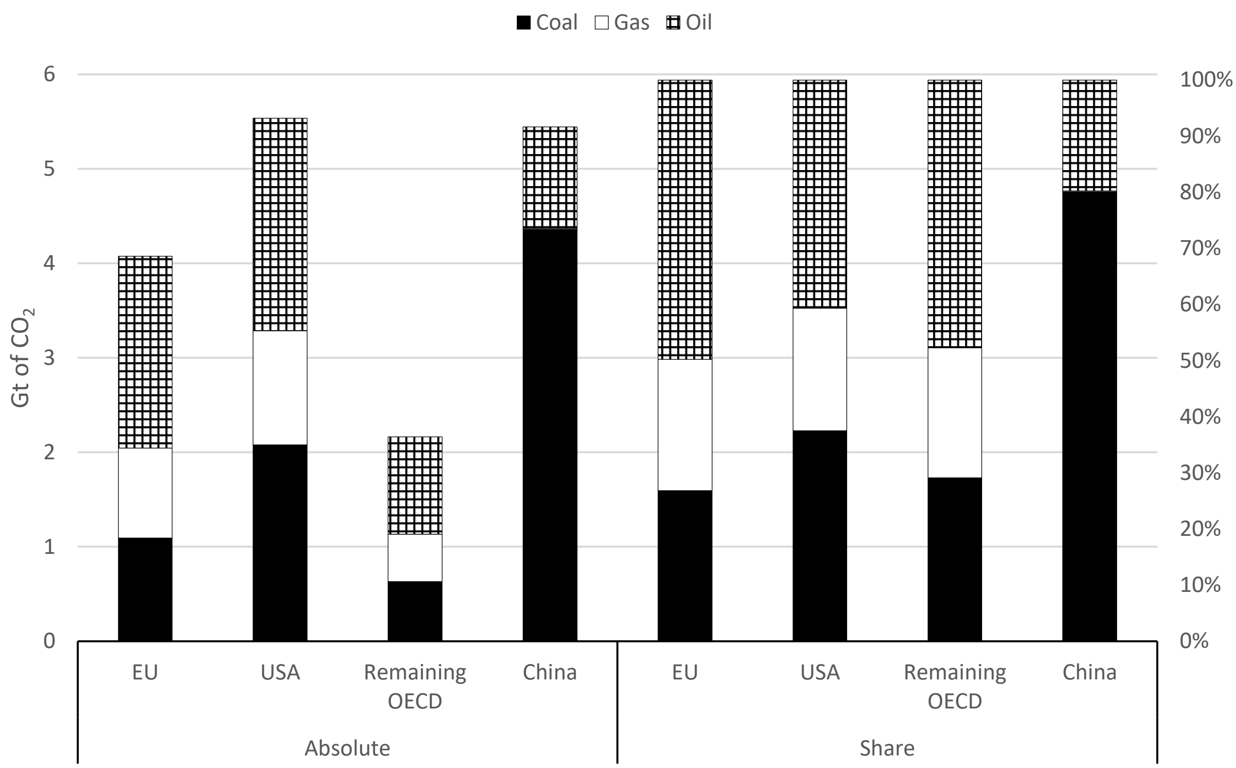
Crude oil supply and consumption

Crude oil supply and consumption patterns are an important driver of market outcomes in our analysis of unilateral climate policies. Besides the residual crude oil demand elasticity, the most important determinant of a cartel’s ability to utilize market power is its market share. Furthermore, the extent to which crude oil consumption subsidies affect policy outcomes is obviously driven by the share of subsidized oil.

Saudi Arabia alone has a market share of 13%, OPEC-core (Saudi Arabia, Kuwait, Qatar, and United Arab Emirates) sums to 21% of world crude oil supply, and OPEC as a whole exhibits 46%. Clearly, joint OPEC decisions when assuming dominant behavior will be markedly more potent than action by only Saudi Arabia or OPEC-core.

On the consumption side, OPEC countries do not play a big role compared to the major oil consumers EU (19% of world supply), the US (21%), and China (9%): OPEC countries combined consume 10% of world supply. Thus, only one tenth of world crude oil consumption is affected when we assume consumption subsidies within OPEC.

Figure 1: Fuel-specific emissions as absolute value in Gt of CO_2 and percentage share for the EU, the US, remaining OECD, and China



Gas imports in EU and Japan

Oil-gas price linkages in the EU or Japan reduce substitution between oil and gas when oil prices change. At first glance, this gives OPEC an additional incentive to cut back supply when acting dominantly. At second glance, however, the price linkage hinders substitution from coal to gas within the EU if the oil price is increased; with emission constraints for the EU, the CO_2 price will go up which disincentivizes OPEC to curtail oil supply. At the same time, gas consumption in Japan is disincentivized when prices are linked and the oil price increases, which stimulates substitution away from gas. In total, leakage to Japan could either decrease or increase (note that we only consider oil-gas price linkage with the EU as the unilaterally abating region).

The effects of oil-gas price linkages for the EU and Japan depend on the respective gas import shares in overall domestic fossil fuel use. In both regions, gas is a major fuel source with a share of 26% of energy use in the EU and 19% in Japan. More than two thirds of EU's consumed gas is imported, in Japan more than 95%.

5. Policy scenarios and simulation results

5.1. Policy scenarios

Our analysis investigates the effects of unilateral climate policies for alternative assumptions of OPEC behaviour. We adopt the core setting as of Böhringer, Rosendahl and Schneider (2014), i.e., with the EU as the unilaterally abating region. In addition we vary key assumptions about (i) the size of the climate coalition, (ii) the size of the oil cartel, (iii) oil-gas price linkages in the EU and Japan, and (iv) subsidies to domestic oil consumption in OPEC. The base-year data for 2011 provided by GTAP 9 characterizes our business-as-usual (see Section 4), and all scenarios are simulated with respect to this business-as-usual. If not denoted otherwise, simulation results below are reported as percentage changes compared to the business-as-usual.

Core setting

The core setting refers to unilateral climate policy on behalf of the EU[6] and distinguishes two different assumptions about OPEC's behavior (see Table 2): OPEC either behaves competitively as a price-taker (*COM*) or as a dominant producer, exploiting its market power and rationing crude oil supply in order to maximize crude oil profits (*DOM*). In the *COM* scenario, the EU reduces its emissions by 20% compared to business-as-usual via uniform CO_2 emission pricing.[7] In the *DOM* scenario, EU's emission reduction target is scaled endogenously such that the global level of emissions is the same as under *COM*. If, for example, carbon leakage is reduced in *DOM* compared to *COM* through OPEC's supply decision, the domestic abatement effort of the EU falls below 20% with a respective decrease in the CO_2 price compared to *COM*. Assuring an identical level of global emissions across the two scenarios allows the economic welfare analysis to abstain from the valuation of changes in global emissions.

Table 2: Alternative assumptions about OPEC's behaviour

COM	OPEC behaves as a competitive producer (price taker).
DOM	OPEC behaves as a dominant producer, i.e. OPEC exploits market power to maximize its profit in the oil market.

Scenario extensions

Beyond the the core setting, we consider variations in key asssumptions along four dimensions as listed in Table 3.

[6] The policy scenarios are stylized and hypothetical and do not precisely reproduce enacted or proposed policies.

[7] Emission pricing can take place either through a uniform CO_2 tax or a EU-wide emission-cap-and-trade system. The carbon payments go lump sum to the regions representative agent. We acknowledge the importance of revenue recycling, see e.g. (Parry, 1995). However, it is beyond the scope of this study to account for different revenue recycling schemes in order to e.g. reduce pre-existing tax distortions.

Firstly, OPEC's strategic scope and incentives to act strategically might change when facing different climate coalitions. Therefore, we investigate additional coalitions of abating countries, i.e.: the EU and the US (denoted *EUxUSA*); the EU, US and China (*EUxUSAxCHN*); OECD (*OECD*); and OECD plus China (*OECDxCHN*). For each climate coalition, the target level of global emission reduction is determined in the same manner as described above for the EU. That is, the global target emerges from a constellation where the abatement coalition joinly reduces its emissions by 20% compared to business-as-usual via a uniform CO_2 price assuming competitive behavior on behalf of OPEC (*COM*).

Secondly, we incorporate variations in cartel size where only OPEC-core – consisting of Saudi Arabia, Kuwait, Qatar, and the United Arab Emirates – or only Saudi Arabia acts as a dominant producer in the *DOM* case.

Thirdly, we introduce a price linkage between the international crude oil price and the import price for natural gas imports in the EU and Japan: the percentage change of gas import prices in the two regions is bonded to the percentage change of the crude oil price.[8]

Fourthly, we consider the a situation where OPEC members – in case of imperfect competition – do not exploit market power on domestic markets, but subsidize crude oil consumption such that domestic consumers pay the producer price.

Table 3: Scenario extensions

Dimension	Description	Acronym
Climate coalition	Coalition of countries that jointly reduce CO_2 emissions to meet a global emission reduction target.	EU; EUxUSA; EUxUSAxChina; OECD; OECDxChina
Cartel size	OPEC members that jointly act as a dominant producer on the international crude oil market.	OPEC; OPEC-core*; Saudi Arabia
Oil-gas price link	Import prices for natural gas in the EU and Japan are linked to the international crude oil price.	NO_LINK; YES_LINK
Oil consumption subsidy	OPEC members subsidize domestic crude oil consumption (in *DOM*).	NO_SUB; YES_SUB

* *Saudi Arabia, Kuwait, Qatar, United Arab Emirates*

[8] Technically, this is implemented through an endogenous export tax (or subsidy) in the exporting regions.

5.2. *Simulation results*

Our discussion of simulation results focuses on the effects on the international crude oil market, leakage rates,[9] and macroeconomic adjustment cost at the regional and global level.[10] We begin with the core setting, where the EU undertakes unilateral climate action and OPEC acts either as a price taker or a dominant producer. Subsequently, we lay out how results change as we vary key assumptions along the four dimensions listed in Table 3.

Core setting

Not surpisingly, the results in our core setting are in line with the findings in Böhringer, Rosendahl and Schneider (2014).[11] Figure 2 summarizes the oil market outcome. If the oil market is perceived as competitive, unilateral emission reduction by the EU induces a crude oil price drop of 0.8%. Accordingly, both OPEC supply and Non-OPEC crude oil supply slightly drop. Oil consumption within the EU decreases by 5.3%, while it increases by 0.8% outside the EU, indicating leakage through the oil market. Looking at leakage in more detail, Figure 3 decomposes the overall leakage rate into leakage rates for coal-, gas-, and oil-related emissions. We see that overall leakage amounts to 19%, with about a third stemming from leakage through the oil market.

If OPEC behaves as a dominant producer, results look quite different. OPEC cuts back crude oil supply by 3.1% and as a consequence the international oil price increases by 0.6%. Crude oil consumption outside the EU drops marginally by 0.02%, i.e., we obtain a slight negative oil-related leakage.[12] Leakage through the coal and gas markets slightly increases compared to *COM* due to substitution away from oil. The reason for OPEC's incentive to cut back supply and increase the international crude oil price is strategic rent seeking: Higher oil prices lead to less oil consumption in- and outside the EU; with a fixed global target for CO_2 emissions, higher oil prices attenuate leakage and thereby relax the EU emissions constraint. As a consequence, the EU-wide CO_2 price drops.[13] This mechanism enables OPEC to convert part of the EU's carbon rents into domestic crude oil rents by cutting back crude oil supply.

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[9] The leakage rate is defined as the ratio between emission increases in unregulated regions and emission reductions in regulated regions.

[10] Adjustment costs are reported in terms of Hicksian equivalent variation as a percentage share of business-as-usual (base-year) GDP.

[11] Differences in quantitative results can be traced back to the change in base-year data. While GTAP 8 with the base year 2007 is used in Böhringer, Rosendahl and Schneider (2014), we adopt the more recent GTAP 9 database with the base year 2011 for our current analysis.

[12] Oil consumption outside the EU is in fact driven by two opposing effects: on the one hand, the price increase disincentivizes consumption; on the other hand, net demand for oil-intensive products such as international transport services outside the EU increases as the EU cuts back oil-intensive production under carbon pricing.

[13] The CO_2 price within the EU is 51 USD/tCO_2 in *COM* and 44 USD/tCO_2 in *DOM*, see Table 4 below.

Figure 2: Crude oil market effects in the core setting under *COM* and *DOM*

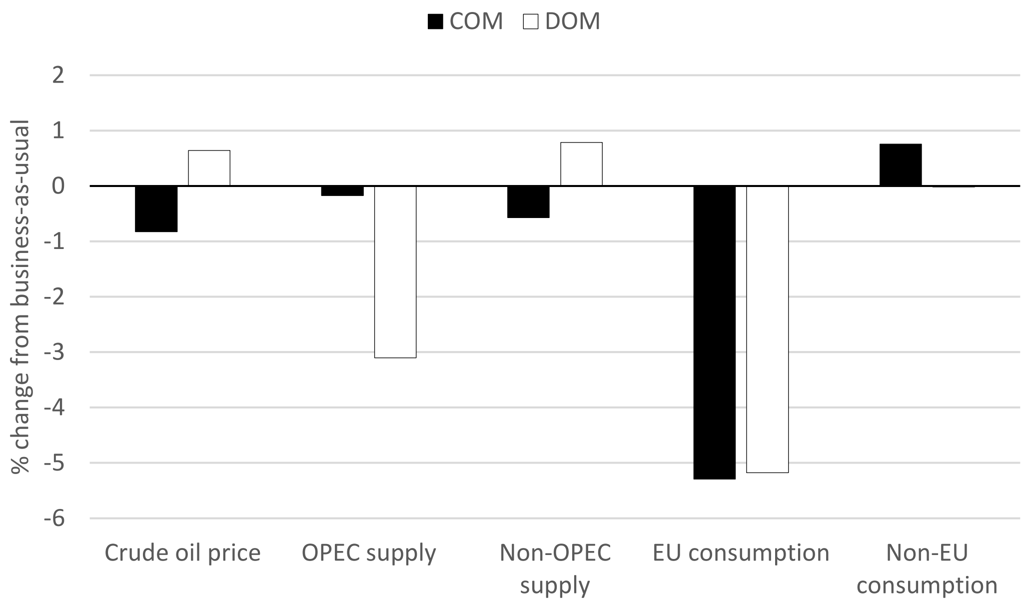


Figure 3: Total and fuel-specific leakage rates (in %) in the core setting

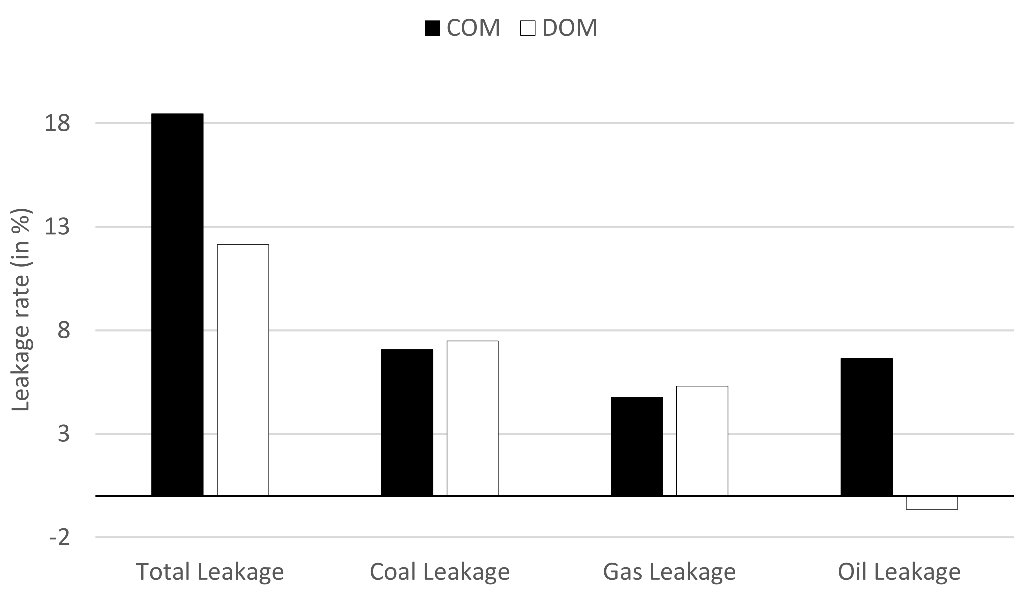
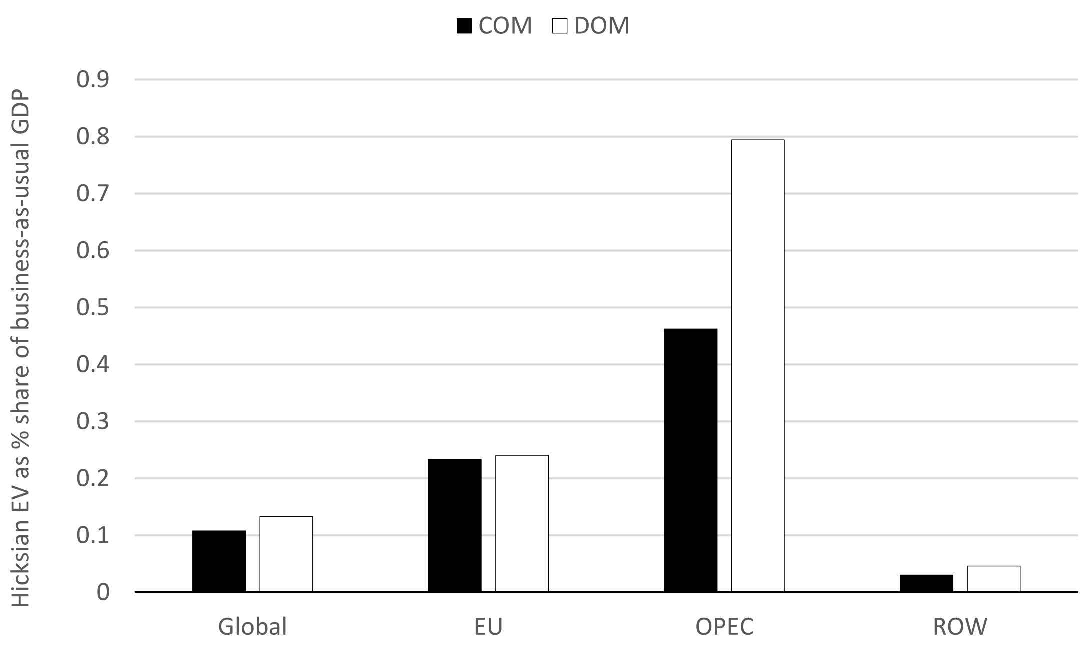


Figure 4 shows the economic adjustment costs of unilateral climate policies at the global level as well as across specific regions, here: EU, OPEC and the rest of the world (ROW). Global adjustment costs are more than one third higher under the assumption of dominant OPEC behavior (*DOM*) compared to a competitive market structure (*COM*). Due to OPEC's strategy to increase the oil price under *DOM*, too much mitigation takes place through reduced oil consumption and the consequential substitution to other fuels deteriorates efficient CO_2 emission abatement via fuel switching. The differential assumptions on the oil market structure have important implications not only for the magnitude but also for the distribution of economic adjustment cost to unilateral climate policy. Already under *COM*, OPEC is hit hard as EU's demand for oil drops significantly together with a slight decline in the international crude oil price – thus leading to a marked decrease in OPEC's oil export revenues. If we rather assume that OPEC acts as a dominant producer, its adjustment costs are much higher in relative terms compared to a competitive market setting (0.8% of business-as-usual GDP under *DOM* compared to 0.46% under *COM*). The reason is that market power is characterized in the business-as-usual by markup earnings in OPEC, parts of which are lost through reduced oil demand under EU's climate policy.[14]

On economic adjustment costs in the EU, the higher oil price under *DOM* as a strategic response to unilateral emission pricing has two opposing effects. On the one hand, distorted fuel substitution reduces the cost-effectiveness of domestic abatement compared to *COM*. On the other hand, OPEC's strategic response leads to lower emissions in non-EU countries, implying reduced leakage rates and thus relaxes the domestic CO_2 constraint for a fixed global level of emissions. In total, adjustment costs for the EU are nearly identical under the two alternative settings. The rest of the world faces about one and a half times higher costs under *DOM* compared to *COM*, however at a rather low level of 0.05% of business-as-usual GDP.

Figure 4: Global and regional adjustment costs in the core setting

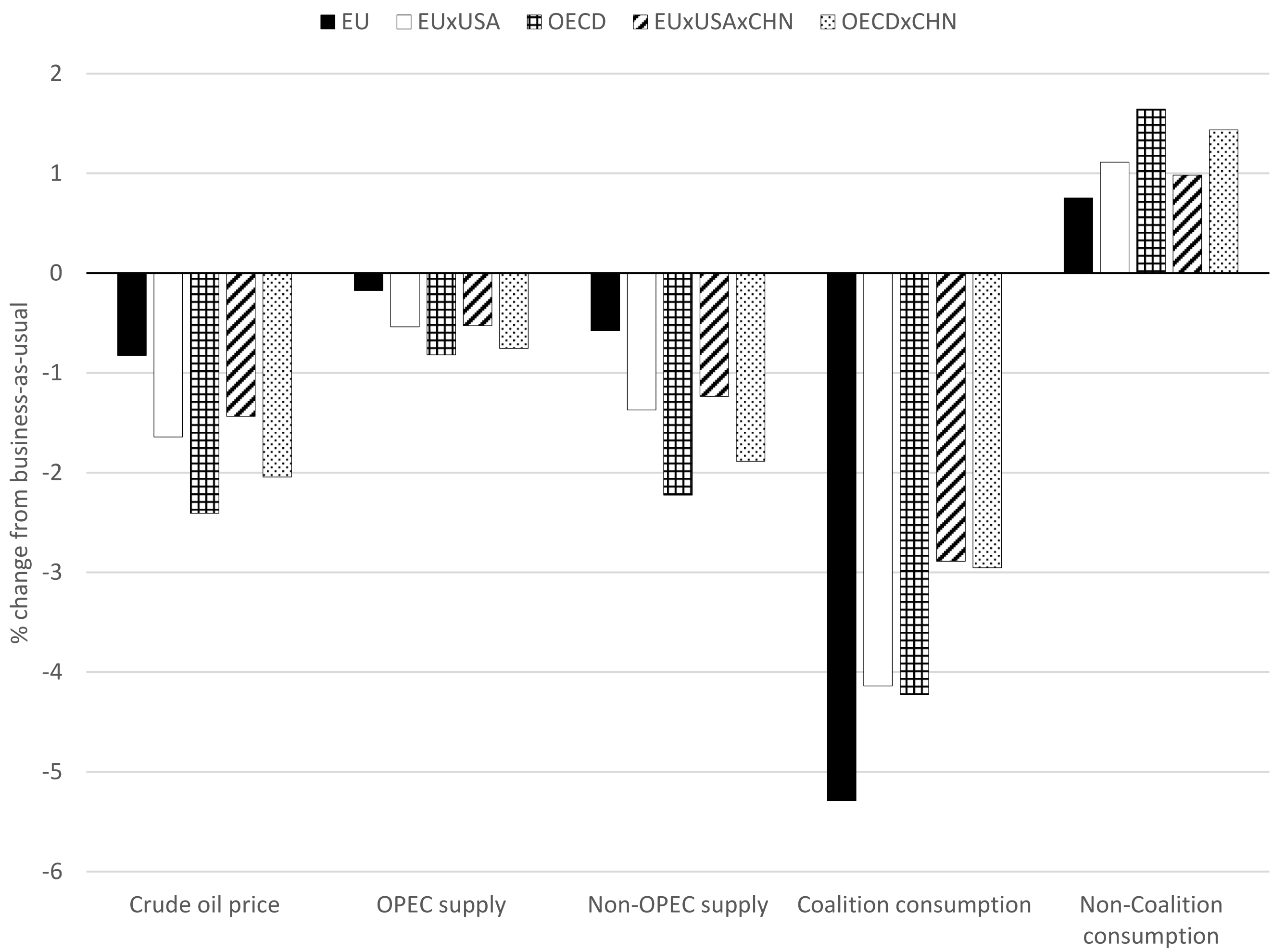


[14] Note that *COM* and *DOM* require two different benchmark calibrations for OPEC. Hence, caution is needed when comparing the adjustment costs for OPEC under *COM* and *DOM*.

Climate coalition

The impacts of unilateral emission pricing hinge critically on the size and composition of the abatement coalition. Figures 5 and 6 show the economic effects on the international crude oil market for different climate coalitions assuming either competitive *(COM)* or strategic OPEC behavior *(DOM)*.

Figure 5: Crude oil market effects for alternative climate coalitions under *COM*



With competitive oil markets (Figure 5), we see that the drop in the international crude oil price becomes more pronounced as the coalition size increases from EU to include the US (*EUxUSA*) and all other OECD countries (*OECD*): While the EU alone induces a price drop of 0.8%, combined action by the EU and the US decreases the price by 1.6%, and a joint OECD policy leads to a decline of 2.4% reflecting larger cuts in crude oil demand along with the expansion of the coalition size. The changes in OPEC and Non-OPEC oil production as well as in oil consumption by coalition and non-coalition countries are aligned with the observed price reductions. When China joins the coalition – either *EUxUSA* (towards *EUxUSAxCHN*) or *OECD* (towards *OECDxCHN*) – impacts on the crude oil market become slightly attenuated. The reasoning behind is illustrated in Figure 7 joint with Figure 1 (see Section 3): While total emission abatement obviously increases as China joins the climate coalition, abatement of oil-related CO_2 emissions in fact decreases. This is because China supplies a larger amount of low-cost abatement options of coal-related CO_2 emissions to the coalition. Note that abatement in OECD countries is markedly lower when China enters the coalition – the CO_2 price necessary to reach the coalition target of 20% emission reduction declines substantially indicating low cost abatement options in China (see Table 4). With the assumption of a competitive oil market (*COM*), the coalition *EUxUSA* reduces total emissions by 1.9 Gt of CO_2, of which 0.20 Gt are oil-related. If China joins the coalition, total emission reduction amounts to 2.7 Gt of CO_2 with only 0.18 Gt being oil-related. As a consequence, the negative demand shock on the crude oil market is reduced. Leakage rates are reported in Figure 8 and – as expected – decline with the coalition size: from 19% for the EU to 3.7% under joint action for the coalition of OECD and China.

Figure 6: Crude oil market effects for alternative climate coalitions under *DOM*

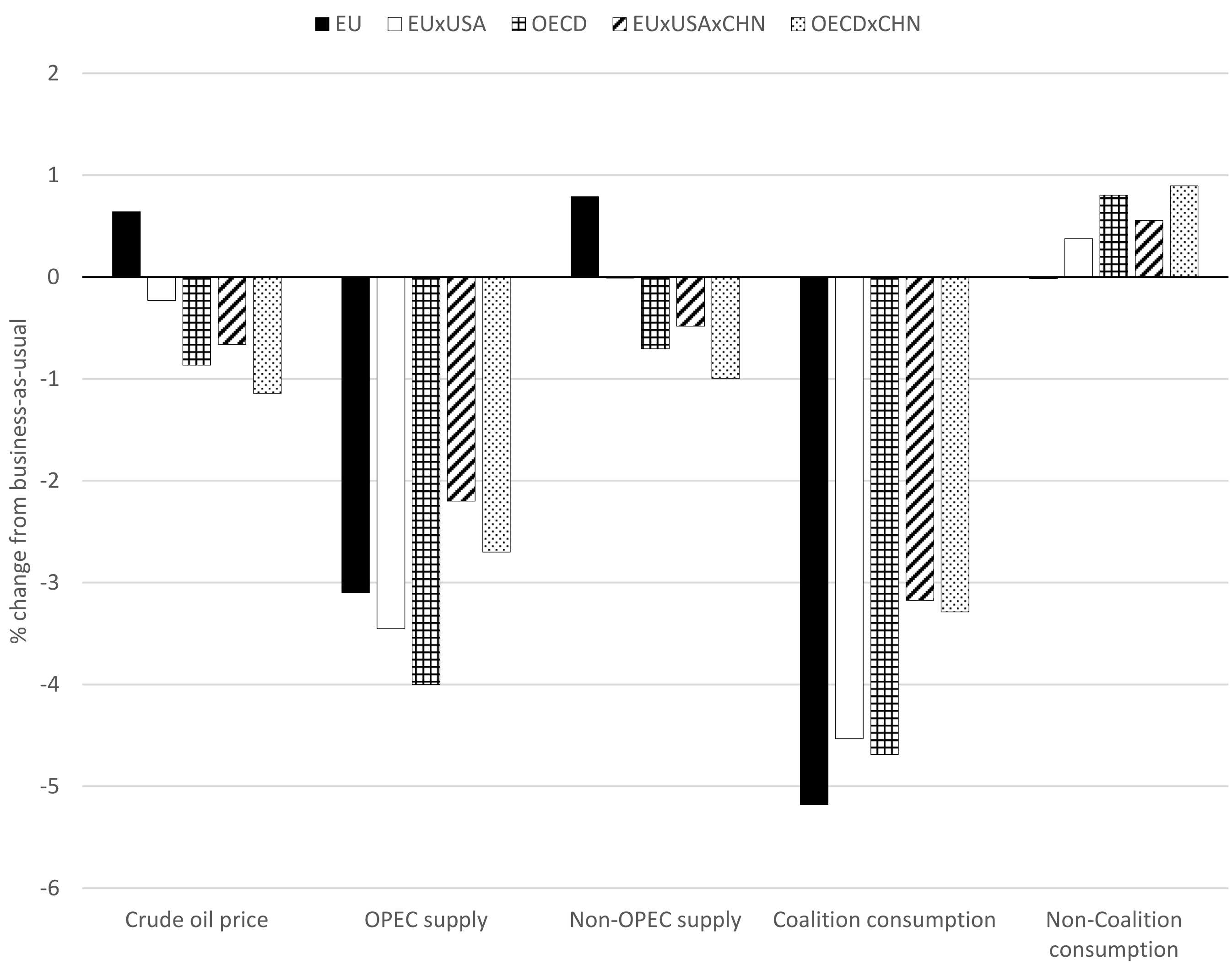
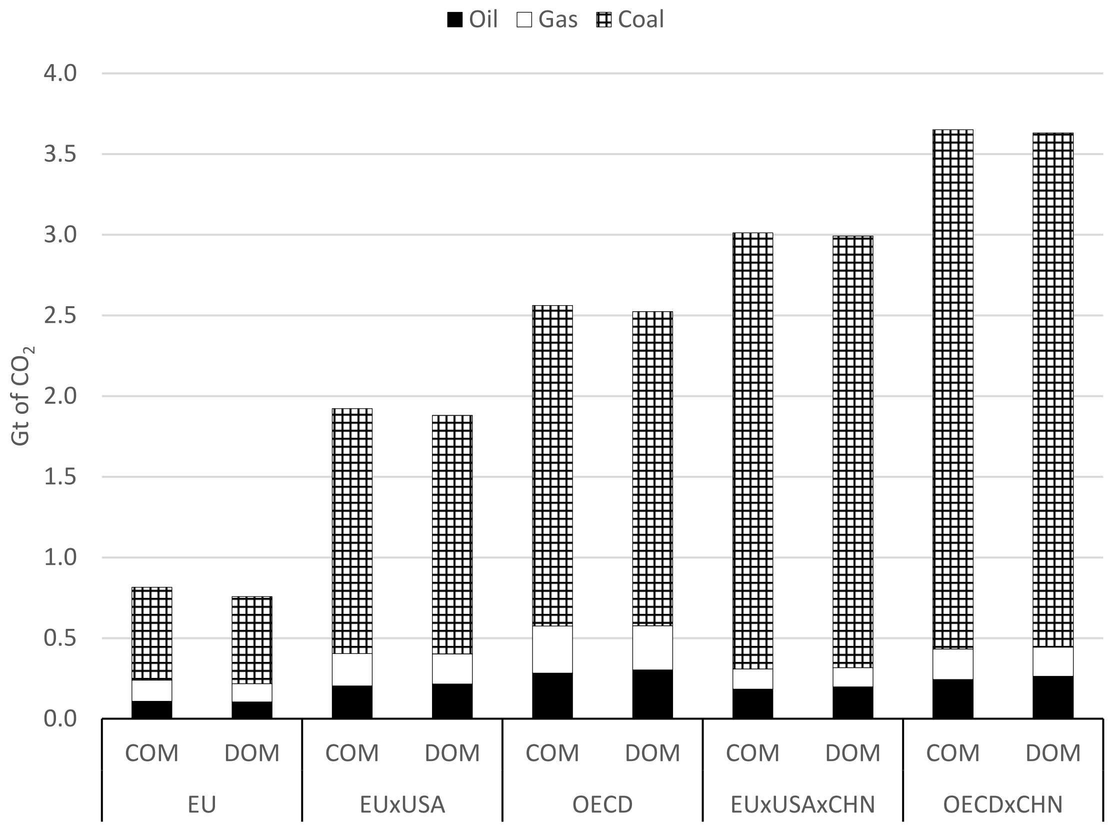


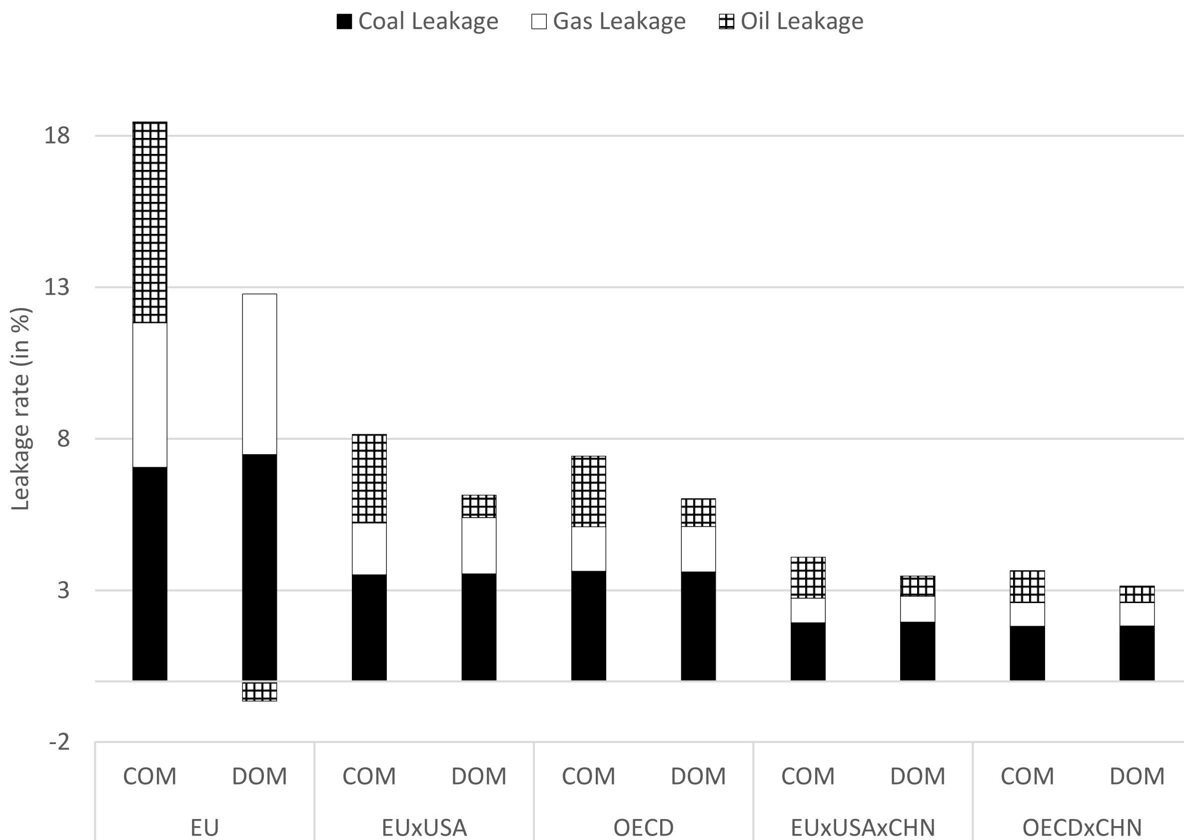
Figure 7: Decomposition of the CO_2 emission reduction in Gt of CO_2 according to oil-, gas-, and coal-related emissions for alternative climate coalitions under *COM* and *DOM*



If we turn to the cases where OPEC acts as a dominant producer (Figure 6) and compare it to the competitive market case (Figure 5), we find a similar outcome as in the core setting when looking at each coalition individually: OPEC reduces supply significantly more under *DOM* than under *COM*; as a consequence the oil price is markedly higher. However, our core setting where the EU acts unilaterally is the only scenario where the oil price change is positive. Towards the larger coalitions the initial negative demand shock in the oil market associated with the coalition's emissions constraint is too big to achieve a price increase vis-à-vis the business-as-usual.

Similar to the cases with perfect competition, the initial demand shock, the price drop as well as OPEC's cutback in supply are increasing as the USA or other OECD countries join the EU in the abatement coalition. However, this does no longer hold when we take the coalitions including China into consideration. In these cases, OPEC has a significantly lower incentive to cut back supply. If we start from an initial coalition compromising the EU and the USA where OPEC decrease supply by 3.5% (compared to business-as-usual), the effects of adding other OECD regions versus adding China are quite different. With other OECD countries joining the coalition, OPEC decreases supply further to 4.0%. With China joining the abatement coalition, OPEC supply is no longer cut by 3.5% but only by 2.2%.

Figure 8: Total and fuel-specific leakage rates for alternative climate coalitions under *COM* and *DOM*



Key to OPEC's incentives for curtailing crude oil production is its ability to impact the CO_2 price within the climate coalition and thereby shifting over emission regulation rents.[15] Table 4 shows the CO_2 prices across the five abatement coalitions. We see that for unilateral abatement of the EU, OPEC's supply decision leads to a pronounced decline in the CO_2 price by 7 USD/tCO_2 from 51 USD/tCO_2 to 44 USD/tCO_2. For the two coalitions including China, the price drop between *COM* and *DOM* amounts only to 0.4 USD/tCO_2. There are two intertwined drivers of OPEC's strategic scope to shift rents. Firstly, the amount of CO_2 emission reduction within the coalition that is achieved through reduced oil consumption (Figure 7): If this amount is substantial, OPEC can to a larger degree substitute the CO_2 price with a higher crude oil price. Secondly, the (oil-specific) leakage rate: If there is substantial leakage through the oil market, OPEC can reduce the coalition's CO_2 price through a higher crude oil price (recall that the coalition pursues a fixed target for global emission reductions). Both drivers for OPEC's strategic power become weaker when China joins the abatement coalition. With China being part of the abatement coalition, less abatement is achieved via reduced oil consumption. At the same time, the problem of leakage and in particular oil-specific leakage is less

[15] This is analytically laid out in equation (5) in Appendix A.

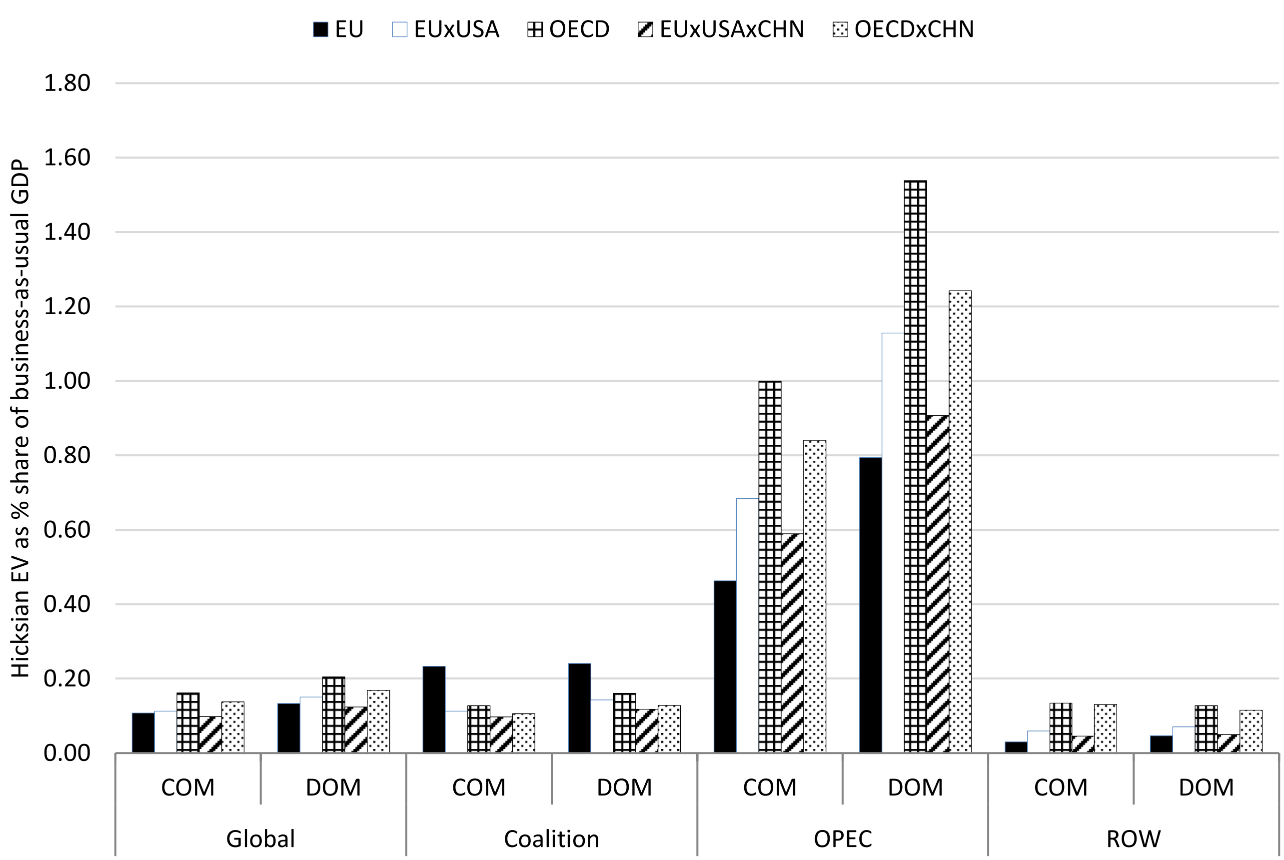
pronounced in percentage terms (China joining a coalition roughly halves overall leakage rates as well as oil-specific leakage rates – see Figure 8).

Table 4: CO_2 price in USD per ton of CO_2 for different climate coalitions under *COM* and *DOM*

	EU	EUxUSA	OECD	EUxUSAxCHN	OECDxCHN
COM	51.3	35.7	38.6	22.5	25.4
DOM	44.1	33.8	36.9	22.1	25.0

Regarding leakage, we find the same pattern for different coalition sizes as in the core setting when switching from *COM* to *DOM*: The overall leakage rate drops because oil-related leakage is reduced substantially along with OPEC's cutback in crude oil supply. Coal- and gas-related leakages increase due to substitution away from oil. The EU remains the only case where oil-related leakage actually turns negative (see the respective oil market outcomes displayed in Figure 6).

Figure 9: Global and regional adjustment costs for alternative climate coalitions under *COM* and *DOM*



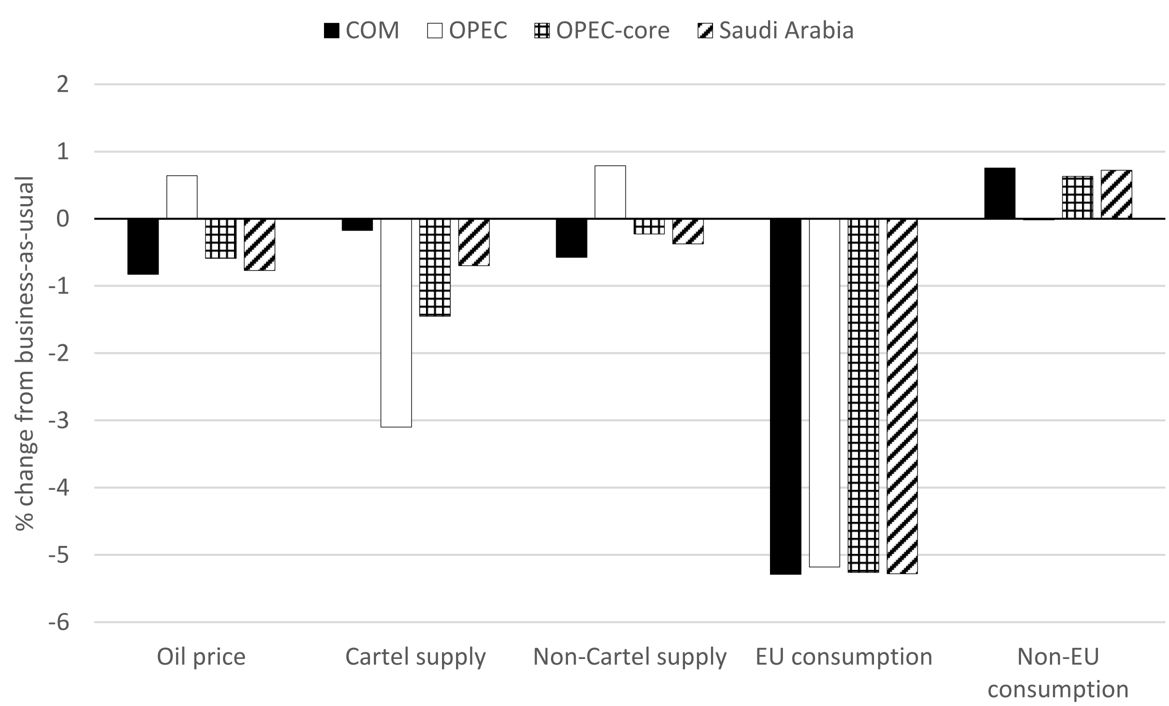
Economic adjustment costs at the global and regional level are reported in Figure 9. For each individual coalition, the same logic applies as in the core setting: imperfect competition in the crude oil market increases global costs and a major share in the burden is borne by OPEC itself. Again, it becomes obvious that China supplies plenty of low-cost abatement options to the coalition – not only global costs but also the coalitions', OPEC's, and the rest of the world's (ROW) costs decline as soon as China joins either the EU and USA, or OECD as whole.

Cartel size

Next we investigate the implications of changes in the oil cartel size. We compare three cases where either OPEC as a whole, OPEC-core – consisting of Saudi Arabia, Kuwait, Qatar, and United Arab Emirates – or only Saudi Arabia exerts market power.

Figure 10 shows the outcomes in the crude oil market for the different cartel sizes in comparison to the competitive market setting (*COM*).[16] The effects on the crude oil market get more similar to the competitive market outcome (*COM*) as the cartel size declines, i.e. when we consider OPEC-core or Saudi Arabia instead of OPEC as a whole. While the crude oil price *increases* by 0.64% as an optimal response to EU's climate policy with OPEC as a dominant producer, the price *drops* by 0.59% and 0.77%, respectively, when OPEC-core or Saudi-Arabia acts strategically. In the competitive setting, the price drops by 0.82%. The price changes are mirrored by respective supply decisions of the cartel.

Figure 10: Crude oil market effects under *COM* and for different cartel sizes



[16] Obviously, results under *COM* are identical for the different assumptions on the cartel size.

Accordingly, leakage only drops to 17.5% in case of OPEC-core and 18.2% in case of Saudi Arabia stand-alone (compared to 18.5% under *COM* – see Figure 11). The impacts on the leakage rate are mainly driven by the initial (business-as-usual) cartel's share of world crude oil supply, which amounts to 46% for OPEC, 21% for OPEC-core and 13% for Saudi Arabia (see Section 3). Only OPEC as whole exhibits sufficient market power to effect larger changes under *DOM* as compared to *COM*.

Figure 11: Total and fuel-specific leakage rates for different cartel sizes

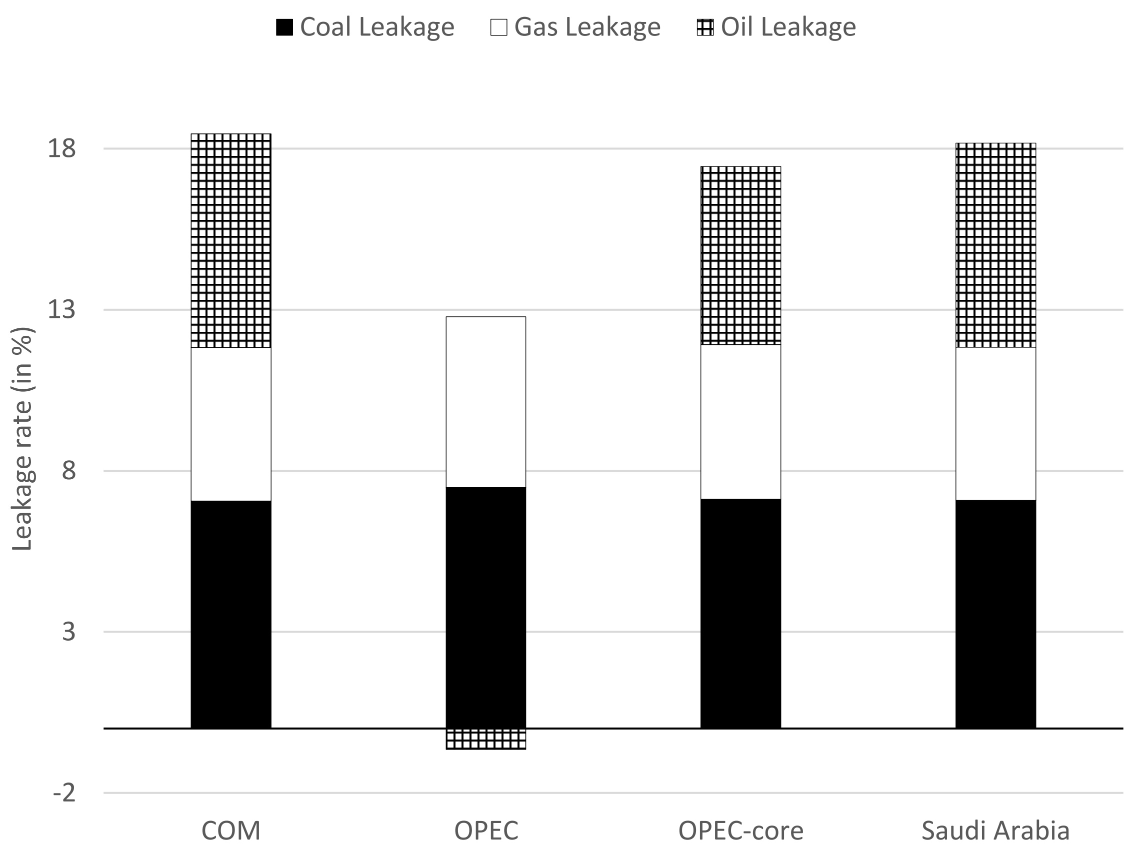
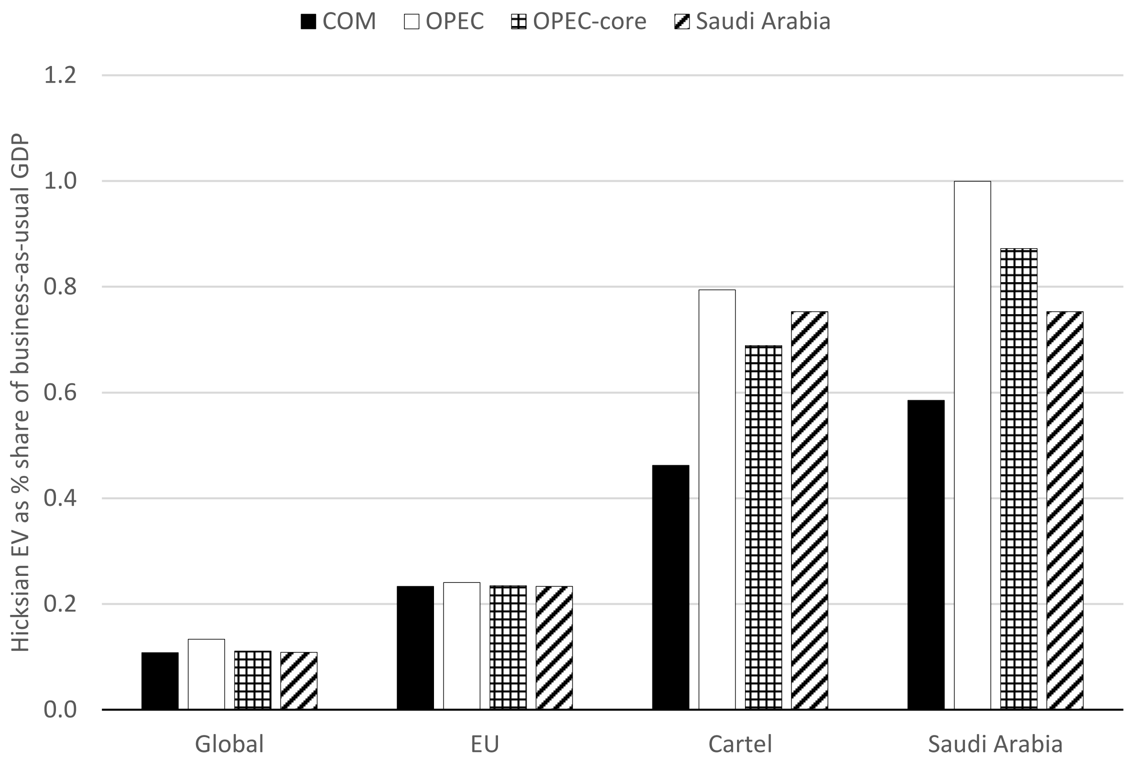


Figure 12 depicts economic adjustment costs at the global and regional level across different cartel sizes. As the group of dominant producers becomes smaller and the oil market transits towards a competitive setting, global adjustment costs due to unilateral abatement of the EU decline. In terms of adjustment costs, Saudi Arabia is best off when it forms the cartel stand-alone. As the biggest crude oil producer, Saudi Arabia bears the largest part of the burden across OPEC countries when all OPEC countries act jointly as a dominant producer.[17]

[17] Note that each assumption on who exhibits market power in the crude oil market – OPEC, OPEC-core or Saudi Arabia – requires a coherent benchmark calibration. The initial markup which is consistent with base-year data is the smallest for the assumption where Saudi Arabia

Figure 12: Global and regional adjustment costs for different cartel sizes



Oil-gas price linkages and OPEC oil consumption subsidies

Figures 13-15 summarize the outcome on the crude oil market, total and fuel-specific leakage rates, as well as global and regional cost implications for the cases of an oil-gas price linkage (*COM&YES_LINK*, *DOM&YES_LINK*) or domestic consumption subdsidies in OPEC (*DOM&YES_SUB*).[18]

Linking import prices for natural gas in the EU and Japan with the crude oil price gives two opposing incentives to OPEC when acting strategically. On the one hand, the price link reduces substitution from oil to gas in the affected regions triggered by oil price increases; OPEC thus faces an additional incentive to increase crude oil prices and cut back supply. On the other hand, the linkage hinders substitution from coal to gas, which exerts an upward pressure on the CO_2 emission price given a fixed (constant) global emission constraint.; this in turn affects demand for crude oil negatively and provides an incentive to keep the oil price low.

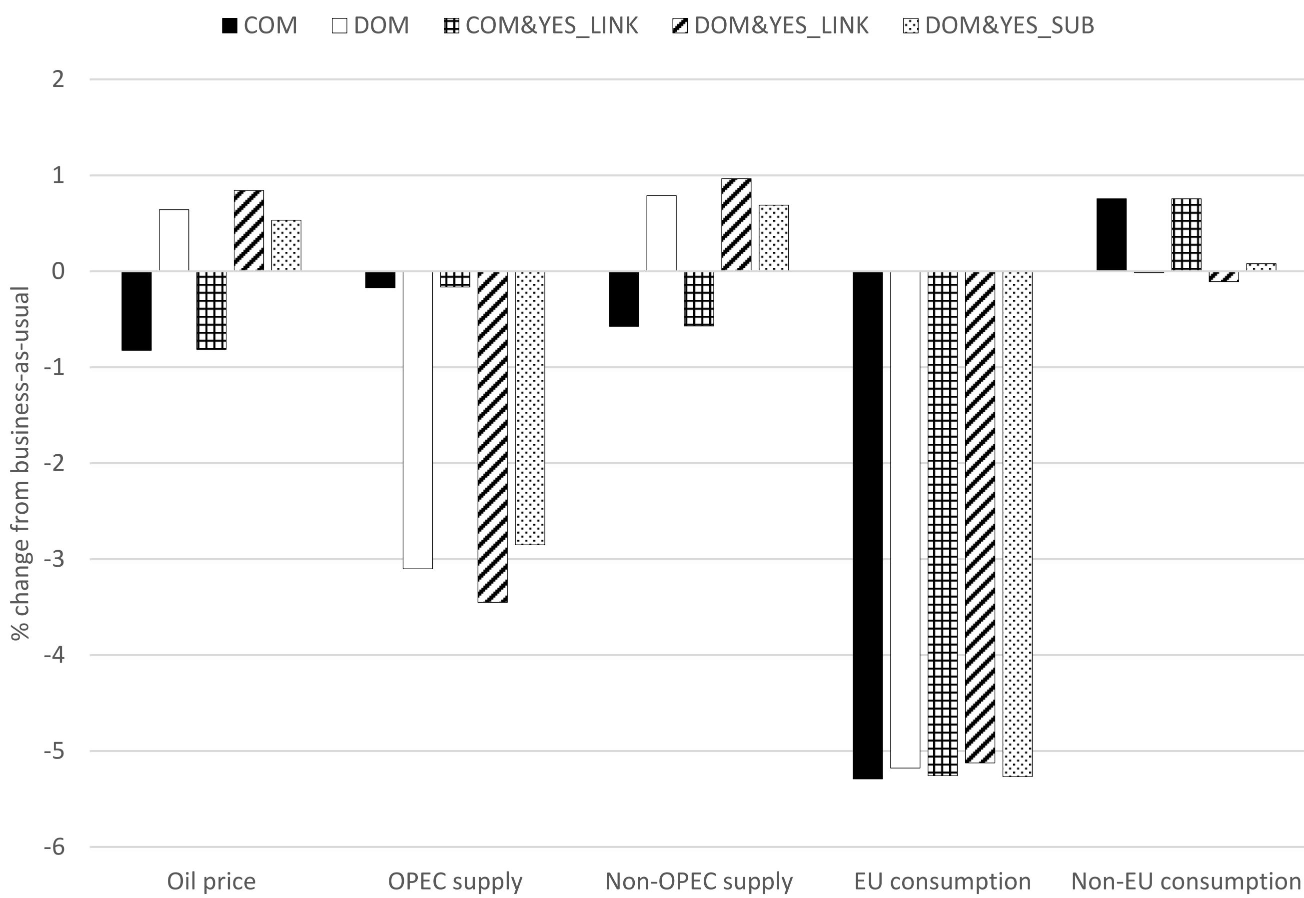
represents the cartel stand-alone. As a consequence, Saudi Arabia earns less from its crude oil production already in the business-as-usual (by assumption), and is thus hit less hard in relative terms by a negative demand shock in the crude oil market. Hence, caution is needed when comparing these numbers.

[18] The case *COM&YES_SUB* is identical to *COM* since there is no markup in OPEC's oil production.

For a competitive oil market setting, the price link has almost no influence. Assuming strategic OPEC behavior, we observe an oil price increase by 0.84% with a price link compared to 0.64% without – in other words, the incentive to further increase the crude oil price slightly prevails.

Gas imports in the EU decrease only by 1-2 percentage points in scenarios with oil-gas price linkage compared to no price linkage. Leakage drops to 11.4%, which is slightly less than without price linkage. In particular, leakage to Japan drops from 0.36% to 0.04% as gas imports decrease by 0.5% compared to an increase of 1.1% without price link.

Figure 13: Crude oil market effects with an oil-gas price link and consumption subsidies



If we assume that domestic crude oil consumption within OPEC is subsidized (*YES_SUB*), we obtain very similar results to the the core setting with respect to oil market outcomes, leakage rates, and cost implications (comparing *DOM&YES_SUB* with *DOM* in Figures 13-15). This is not very surprising given that OPEC subsidies apply to less then 10% of world crude oil consumption. OPEC cuts back supply by 2.9% under *DOM&YES_SUB* compared to 3.1% in the core setting without subsidies. The oil price increases are 0.53% and 0.64%, respectively. The only remarkable change that occurs for the case of oil subsidies is that the share of OPEC oil consumption in global crude oil consumption increases by 0.9% compared to 0.1% under *DOM*. Consumption in the EU, on the other hand, drops by 5.3% (*DOM&YES_SUB*) and 5.2% (*DOM*), respectively.

Figure 14: Total and fuel-specific leakage rates with an oil-gas price link and consumption subsidies

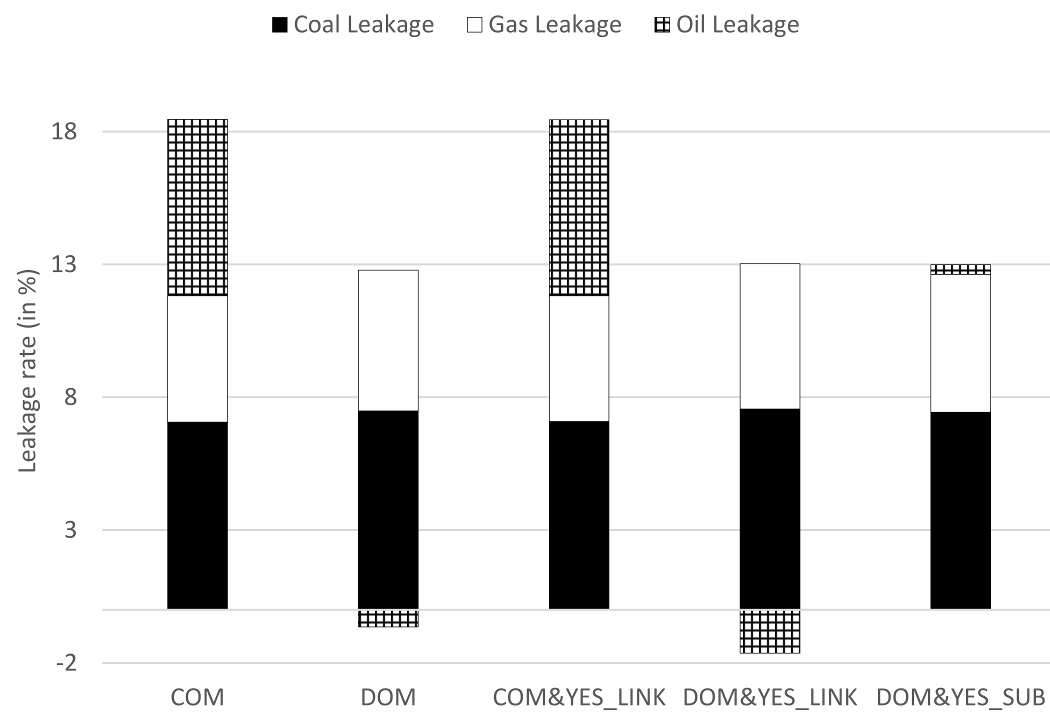
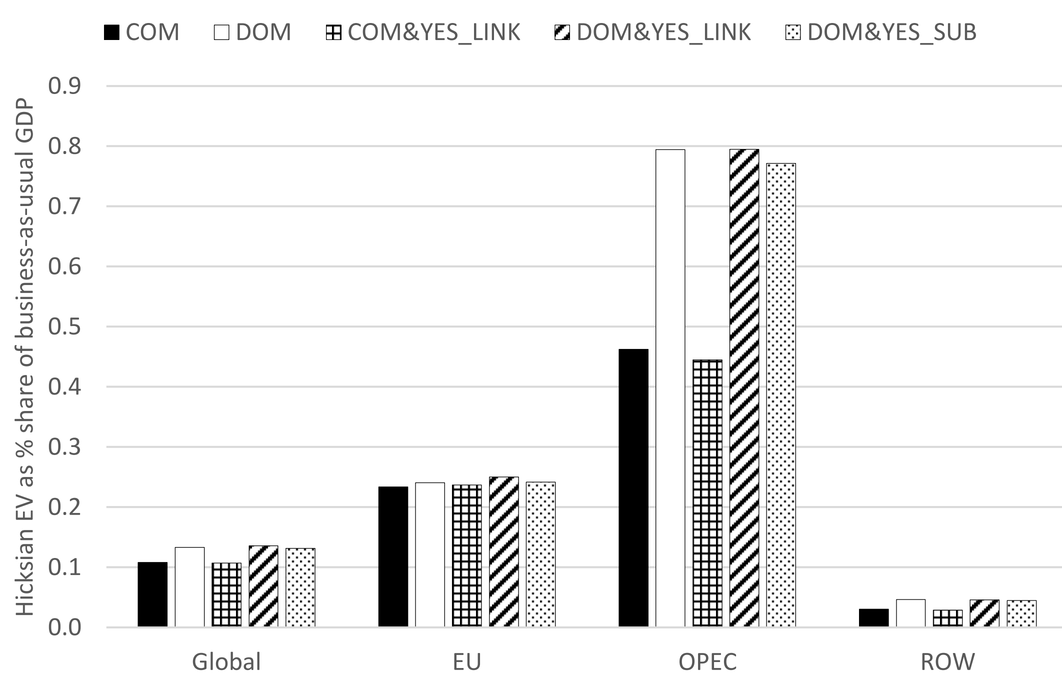


Figure 15: Global and regional adjustment costs with an oil-gas price link and consumption subsidies



5.3. Sensitivity analysis

In order to test the robustness of our main insights we perform sensitivity analysis on five key policy and parameter assumptions in our scenarios. We focus on the first dimension of our scenario extensions, namely the coalition size, as these scenarios brought about the largest deviations from our core setting.

Specifically, we apply scenarios with (a) lower and higher emission reduction targets for the coalition; (b) lower and higher trade responsiveness to price changes; (c) lower and higher fossil fuel supply elasticities; (d) stylized US shale oil and shale gas supply; and (e) lower and higher energy demand elasticities.

Qualitative insights and conclusions from our central case setting remain robust throughout our sensitivity analysis: OPEC's ability to impact on the coalitions CO_2 price through strategic supply decisions hinges critically on the climate coalition and is particularly lower when China is part of the coalition. Nonetheless, the sensitivity analysis reveals important implications of the specific assumptions.

Along (a), we find that the leakage rate increases slightly with the reduction target. Furthermore, we find that oil leakage marks a larger share of total leakage as the reduction target (and hence the endogenous CO_2 emission price) rises due to an increasing net demand for oil-intensive products outside the coalition (see footnote 14).

As to (b), OPEC's ability to act strategically in the *DOM* scenario is not much affected by the trade responsiveness.

Regarding fossil fuel supply (c), we find that OPEC's ability to act strategically depends crucially on the price responsiveness of Non-OPEC oil producers. With high supply elasticity, the oil price drops when the climate policy is introduced, irrespective of which climate coalition we consider, whereas with low supply elasticity, the oil price increases even when China is part of the coalition.

Respecting for the employment of new extracting technologies in the US (d) by increasing US supply elasticities, OPEC is less able to exercise market power as US supply reacts more swiftly to price changes. Even under the EU coalition the oil price no longer increases but slightly drops. Market outcomes under *DOM* move closer towards a competitive market.

Lower energy demand elasticities (e) require higher endogenous CO_2 prices to effect the same emission reduction, which ceteris paribus leads to higher leakage rates through larger competitiveness losses of domestic emission-intensive and trade-exposed industries. At the same time, they reduce leakage that is stimulated through reduced international energy prices. In the *DOM* case we find that OPEC's incentive to cut back supply *inreases* with the assumed global energy demand elasticity. The reason is that the optimal markup in the business-as-usual is lower if the demand elasticity is higher.[19] Then the impact of the emission cap (setting the demand elasticity de facto to zero if we disregard fuel-switching) on the optimal markup is more pronounced when the benchmark demand elasticity is higher.

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[19] See equation (3) in Appendix A.

Thus, assuming a higher demand elasticity already in the benchmark, the introduction of the cap induces a higher incentive for OPEC to cut back supply.

A more detailed description of the sensitivity analysis results is provided in Appendix B, where the outcomes for all scenarios are shown in Tables B.2-B.6 at the end of the Section.

Furthermore, the model framework we apply is static, and a relevant question is how our results might change in a dynamic setting where expectations on how the climate policy develops over time play a central role as reflected in the green paradox literature (see Section 2). For instance, if the emissions cap is expected to become more ambitious, oil producers may want to accelerate supply. The basic mechanisms identified in our static framework are still present and will tend to mitigate the near-term supply increase by the dominant producer if the green paradox materializes. The net effect will of course depend on the relative strengths of these two effects.

6. Conclusions

Böhringer, Rosendahl and Schneider (2014) show that imperfect competition in the oil market may have substiantial influence on leakage and economic adjustment cost triggered by unilateral EU climate policies. Oil-related leakage may even turn negative due to OPEC's incentives to increase the oil price compared to business-as-usual.

In the current paper, we have tested the robustness of these findings by changing key assumptions along four dimensions: (i) the size and composition of the climate coalition, (ii) the size of the crude oil cartel, (iii) linkages between the crude oil price and gas import prices in the EU and Japan, and (iv) subsidies to domestic oil consumption in OPEC countries.

Our analysis indicates that OPEC's ability to lower the coalition's CO_2 price and thus to shift over rents is reduced markedly when China becomes part of the abatement coalition. The reason is that China provides lots of low-cost coal-related abatement options to the coalition. As a consequence, effects on the oil market get attenuated, and likewise OPEC's strong incentive to cut back crude oil supply. Regarding the implications of cartel size, we find that when only OPEC-core or Saudi Arabia act dominantly instead of OPEC as a whole, the respective economic effects resemble to a large extent the results for a fully competitive crude oil market setting: The cartel's market share in these cases is simply not large enough to impact markedly on the coalition's CO_2 price. A price linkage between the crude oil price and gas import prices gives opposing incentives to OPEC when assuming dominant behavior, which in total leads to a market outcome which is similar to the case without the price link. Likewise, subsidies to domestic consumers in OPEC do not markedly change OPEC's supply decision when facing an EU climate policy.

To conclude: Although OPEC's behaviour may be of importance for the extent of carbon leakage, the phenomenon of negative oil-related leakage identified in Böhringer, Rosendahl and Schneider (2014) seems to be of less policy relevance when adopting alternative assumptions. The oil cartel's effects on leakage depend most significantly on the size of the cartel, the size of the climate coalition, and the price responsiveness in the oil market, particularly with respect to Non-OPEC supply.

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Appendix A

In this appendix we provide a simplified analytical description of how the dominant producer reacts to the climate policy implemented by the climate coalition.[20] The underlying assumption behind the dominant producer model is that the dominant producer maximizes profits, taking into account price responses both on the demand side and among other producers.

Let x_j denote production of producer (group) j, where $j = DOM$ (dominant producer), COM (competitive producers). Further, let $x_{COM}(p)$ denote the joint supply function of competitive producers, and $x_D(p)$ the global oil demand function, where in equilibrium $x_D = x_{DOM} + x_{COM}$. Thus, the dominant producer's residual demand function is $x_{DOM}(p) = x_D(p) - x_{COM}(p)$. The maximization problem of the dominant producer can then be written:[21]

[20] A somewhat similar description is also provided in Böhringer, Schneider and Rosendahl (2014).

[21] Note that there is a one-to-one relationship between the oil price and the dominant producer's supply. Hence, we can freely choose whether to maximize with respect to price or production. The dominant producer model is most easily solved when maximizing with respect to the price. In the main text, however, we mostly formulate as though the dominant producer chooses supply rather than the price.

$$\underset{p}{\text{Max}}\left\{\left(x_D(p)-x_{COM}(p)\right)p-c\left(x_D(p)-x_{COM}(p)\right)\right\} \qquad (1)$$

This gives the following first-order condition (with respect to *p*):

$$\left(x_D\,'(p)-x_{COM}\,'(p)\right)p+\left(x_D(p)-x_{COM}(p)\right)-c\,'\left(x_D(p)-x_{COM}(p)\right)\left(x_D\,'(p)-x_{COM}\,'(p)\right)=0 \qquad (2)$$

or (simplifying):

$$p=c\,'\left(x_{DOM}\right)+\frac{x_{DOM}}{\left(x_{COM}\,'(p)-x_D\,'(p)\right)} \qquad (3)$$

The second term on the right hand side is the optimal markup, which is bigger the lower is the price responsiveness of global oil demand and oil supply from competitive producers. If either of these is very price elastic, it is optimal for the dominant producer to choose a price just above marginal costs. Otherwise, it is optimal to choose a more substantial markup.

Assume that the climate coalition imposes a cap on global emissions of CO_2. To simplify, we first disregard emissions from other sources than oil, meaning that there is de facto a (presumably binding) cap on global oil consumption. It is straightforward to show that the first-order condition for OPEC then changes to:

$$p=c\,'\left(x_{DOM}\right)+\frac{x_{DOM}}{x_{COM}\,'(p)} \qquad (4)$$

We see that the only difference between (4) and (3) is that $x_D\,'(p)$ has been removed, which means that the denominator of the markup has declined. This tends to increase the optimal markup, as long as the supply of the dominant producer (the nominator) is not reduced too much. If the cap is only marginally below the business-as-usual (BaU) level, it follows that the oil price will *increase* when the cap is introduced: If the oil price does not increase, competitive supply will not increase, and hence the supply of the dominant producer cannot be reduced more than marginally. Hence, the markup in (4) must exceed the markup in (3) (assuming that the demand elasticity is strictly negative). If the cap is stricter, the nominator in (4) decreases more substantially if the oil price is not reduced, and hence the markup may either increase or decrease. Thus, in this case the oil price may become either higher or lower than the BaU price level.

The explanation for a (possibly) higher oil price is that the dominant producer by assumption knows that the coalition's CO_2 price will adjust endogenously depending on the global oil price. Thus, it is optimal for the producer to try to reap a larger share of the oil rent. This would be different if the coalition instead introduced a fixed CO_2 tax, whereas a cap on emissions *within the coalition* could still lead to a higher oil price (but the likelihood is smaller compared to a cap on *global* emissions). One important implication of a higher oil price is that carbon leakage in the oil market becomes *negative*.

What if we introduce other fossil fuels, which we do in the numerical analysis? Equation (4) then becomes:

$$p = c'\left(x_{DOM}\right) + \frac{x_{DOM}}{\left(x_{COM}'(p) - \frac{\partial x_{D,C}}{\partial p} - \frac{\partial x_{D,C}}{\partial p^F}\frac{\partial p^F}{\partial p} - \frac{\partial x_{D,C}}{\partial p^{CO2}}\frac{\partial p^{CO2}}{\partial p} - \frac{\partial x_{D,NC}}{\partial p} - \frac{\partial x_{D,NC}}{\partial p^F}\frac{\partial p^F}{\partial p}\right)} \tag{5}$$

where $x_{D,C}$ and $x_{D,NC}$ denote oil consumption in the climate coalition and the non-coalition, respectively, and p^F and p^{CO2} denote the price (vector) of other fuels and CO_2, respectively.

Before the climate policy is introduced, the fourth term in the denominator (with p^{CO2}) is not present. When the cap on global emissions is imposed, this term becomes active and is typically negative: A higher oil price reduces demand for oil and hence dampens the pressure on the emissions cap, leading to a lower price on CO_2. Thus, the effect of this term is to increase the optimal markup.

What can we say about equation (5) compared to equation (4)? First, the higher is the share of oil in the global emission account, the more the CO_2 price will respond to oil price changes in order to keep emissions below the imposed cap (cf. $\partial p^{CO2}/\partial p$ in (5)). Second, the more oil consumption reacts to changes in the CO_2 price, relative to other fuel consumption's responses to CO_2 price changes, the more important this mechanism will be for the dominant producer (cf. $\partial x_{D,C}/p^{CO2}$ in (5)). Put differently, the more the CO_2 price channel dampens the reduction in oil demand from a higher oil price, the more profitable it is for the dominant producer to cut back on its oil supply.

Appendix B

We test the robustness of our main insights by varying key policy and parameter assumptions in our scenarios. In this sensitivity analysis we focus on the first dimension of our scenario extensions, namely the coalition size, as these scenarios brought about the largest deviations from our core setting.

We vary key policy and parameter assumptions in five categories, specifically the emission reduction target, trade responsiveness to price changes, fossil fuel supply, US shale oil and shale gas supply, as well as energy demand.[22] To facilitate comparison, Table B.1 summarizes the results on the oil market, leakage, and adjustment costs from our central case setting.

Qualitative insights and conclusions from our central case setting remain robust throughout our sensitivity analylis: OPEC's ability to impact on the coalitions CO_2 price through strategic supply decisions hinges critically on the climate coalition and is particularly lower when China is part of the coalition. However, the sensitivity analysis also shows that OPEC's ability to act strategically depends crucially on the price responsiveness of Non-OPEC oil producers. With high supply elasticity, the oil price drops irrespective of which climate coalition we consider, whereas with low supply elasticity, the oil price increases even when China is part of the coalition.

We describe the main effects that alter the results compared to the central case setting in each category of the sensitivity analysis below. Tables B.2-B.6 show outcomes for the scenarios in the sensitivity analysis. For the sake of readability, we moved result tables to the end of this section.

Reduction target

We consider scenarios with a reduction target of 10% (denoted *RED-10*) and 30% (denoted *RED-30*) to assess the importance of the stringency of climate policy in the coalition. Table B.2 provides the summarized results.

Under the competitive market assumption (*COM*), impacts on the oil market are reduced to slightly less than half with a reduction target of 10% (*RED-10*) and doubled under a 30% target (*RED-30*) across the different coalitions compared to the central case. The leakage rate increases slightly with the reduction target. Furthermore, we find that oil leakage marks a larger share of total leakage as the reduction target (and hence the endogenous CO_2 emission price) rises due to an increasing net demand for oil-intensive products outside the coalition (see footnote 14).

This also explains why oil consumption outside the coalition slightly increases despite an increasing oil price under the dominant producer assumption (*DOM*) in the *RED-30* case (coalition: EU). Thus, oil-related leakage is always positive with the higher reduction target. On the other hand, with the lower reduction target oil-related leakage is negative both with the EU and the EUxUSA coalitions. With bigger coalitions, leakage through the oil market is positive as in the central case setting.

Trade responsiveness

To account for varying degrees of trade responsiveness to relative price changes, we introduce additional scenarios where we either halve (denoted *ARM_lo*) or double (denoted *ARM_hi*) the Armington trade elasticities in the model. The results are summarized in Table B.3.

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[22] Recall footnote 16: differing assumptions about elasticities require different benchmark calibrations. Hence, caution is needed when comparing scenarios in the sensitivity analysis.

Increasing trade elasticities (*ARM_hi*) facilitate relocation of production from coalition to the non-coalition countries. Accordingly, leakage increases somewhat with the trade responsiveness. Also, the coalition is to a lesser extent able to pass through its increasing production cost from carbon pricing and thus bears larger shares of the burden as trade responsiveness increases.

OPEC's ability to act strategically in the *DOM* scenario is not much affected by the trade responsiveness, however, although oil-related leakage turns slightly positive in the case with high trade elasticity and EU as the climate coalition. Besides that, the effects on the oil market and on oil-related leakage are quite similar to the central case.

Fossil fuel supply

As shown in Appendix A (equations (4)-(5)), the price responsiveness of Non-OPEC oil producers is crucial for OPEC's optimal markup. High price responsiveness reduces OPEC's ability to influence the oil price. To investigate the importance of this in our context, we either halve (scenario denoted *FFS_lo*) or double (denoted *FFS_hi*) fossil fuel supply elasticities in the model. The outcomes are summarized in Table B.4.

Under *COM*, lower fossil fuel supply elasticities imply more carbon leakage as negative demand shocks through climate policies lead to smaller cut backs in global supply. If OPEC behaves as a dominant producer (*DOM*), lower supply elasticities augment its incentive to increase the oil price as Non-OPEC producers are to a lesser extent able to step up their supply. Hence, under *FFS_lo* and with the EU coalition, OPEC cuts back its supply by 7%, increasing the oil price by 4%, leading to an oil-related leakage of -20%. Total leakage becomes close to zero. Even under the climate coalitions including China, the oil price slightly increases when supply elasticities are halved, leading to negative oil leakage.

Higher fossil fuel supply elasticities (*FFS_hi*) work the other way around. In this case, the outcomes move closer towards competitive market outcomes (*COM*), and the oil price decreases even in the case with EU as the climate coalition. Thus, we conclude that the price elasticities of oil supply are particularly important for the conclusions about OPEC's behaviour and its influence on oil-related leakage.

US Shale oil and shale gas supply

The surge in shale oil and gas production in the US over the last 5-10 years due to significant improvements in extracting technologies (fracking and horizontal drilling) has had a substantial impacts on the oil and gas markets, and have probably reduced OPEC's ability to combine high prices and high market shares in the oil market (Baumeister and Kilian, 2014). To examine the importance of this in a stylized manner, we include simulations with the fourfold (denoted *US_4*) and eightfold (denoted *US_8*) of the core supply elasticities for crude oil and natural gas in the US. Results are presented in Table B.5.

Under *COM*, higher oil and gas supply elasticities work in the same direction as higher global supply elasticities (see above). Under the dominant producer assumption (*DOM*), OPEC is less able to exercise market power as US supply reacts more swiftly to price changes, such that even under the EU coalition the oil price no longer increases but slightly drops. This effect increases for *US_8* and the market outcome under *DOM* moves closer towards a competitive market (see equations (4) and (5) in Appendix A). We notice that the oil market results in the *US_8* scenarios are quite close to the results in the *FFS_hi* scenarios discussed above.

Energy demand

The analysis in Appendix A shows the relevance of energy demand elasticities for OPEC's optimal markup under the dominant producer assumption (compare e.g. equations (3) and (4)). We introduce scenario *EDE_lo* with a lower energy demand elasticity and *EDE_hi* with a higher energy demand elasticity than in the core setting.[23]

Concerning carbon leakage in the *COM* case, two opposing effects drive the results: on the one hand, lower energy demand elasticities (within the climate coalition) require higher endogenous CO_2 prices to effect the same emission reduction, which ceteris paribus leads to higher leakage rates through larger competitiveness losses of domestic emission-intensive and trade-exposed industries. On the other hand, lower demand elasticities (outside the coalition) dampen leakage that is stimulated through reduced international energy prices. In total, leakage is slightly higher both in *EDE_lo* and in *EDE_hi* than in our central case.

In the *DOM* case, we find that OPEC's incentive to cut back supply *inreases* with the assumed global energy demand elasticity: for the EU coalition, oil leakage remains positive for lower demand elasticities, but is strongly negative with higher demand elasticities. Even for the coalition EU and USA (*EUxUSA*) oil leakage is negative with higher elasticities (under *DOM*). The reasoning is provided in equations (3)-(4) in Appendix A: The optimal markup is higher if the demand elasticity is lower. However, the impact of the emission cap (setting the demand elasticity de facto to zero if we disregard fuel-switching) on the optimal markup is more pronounced when the benchmark demand elasticity is higher. Thus, assuming a higher demand elasticity already in the benchmark, the introduction of the cap induces a higher incentive for OPEC to cut back supply.

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[23] The energy demand elasticity in our framework is endogenous to the cost functions in production. It depends on cross-price elasticities and value shares of inputs. In order to vary the demand elasticity, we either halve (*EDE_lo*) or double (*EDE_hi*) the substitution elasticity in production between energy and value-added. In this way, the own-price elasticity for energy is affected proportionally and for small value shares of energy inputs this cross-price elasticity comes close to the own price elasticity for energy (see e.g. Section 5.1 in http://www.gamsworld.org/mpsge/debreu/ces.pdf). The default value of the cross-price elasticity is 0.5 in our central case; for energy demand elasticities, Steinbuks and Narayanan (2015) find a range of 0.06 to 1.18 for different energy goods and short- or long-run specifications.

Table B.1: Results on oil market, leakage, and adjustment costs in the central case setting

	EU		EUxUSA		OECD		EUxUSAxCHN		OECDxCHN	
	COM	DOM	COM	DOM	COM	DOM	COM	DOM	COM	DOM
Oil market*										
Crude oil price	-0.82	0.64	-1.64	-0.23	-2.41	-0.87	-1.44	-0.66	-2.04	-1.14
OPEC supply	-0.17	-3.10	-0.54	-3.45	-0.82	-4.00	-0.53	-2.20	-0.75	-2.70
Non-OPEC supply	-0.57	0.79	-1.37	-0.01	-2.22	-0.70	-1.24	-0.48	-1.89	-1.00
Coalition consumption	-5.29	-5.18	-4.14	-4.53	-4.23	-4.69	-2.89	-3.17	-2.95	-3.29
Non-Coalition consumption	0.76	-0.02	1.11	0.38	1.65	0.80	0.98	0.56	1.44	0.90
Leakage**										
Total leakage	18.5	12.1	8.1	6.1	7.4	6.0	4.1	3.5	3.7	3.2
Coal leakage	7.1	7.5	3.5	3.5	3.6	3.6	1.9	2.0	1.8	1.8
Gas leakage	4.8	5.3	1.7	1.9	1.5	1.5	0.8	0.9	0.8	0.8
Oil leakage	6.6	-0.6	2.9	0.7	2.3	0.9	1.4	0.7	1.1	0.6
Adjustment costs***										
Global	0.11	0.13	0.11	0.15	0.16	0.20	0.10	0.12	0.14	0.17
Coalition	0.23	0.24	0.11	0.14	0.13	0.16	0.10	0.12	0.11	0.13
OPEC	0.46	0.79	0.68	1.13	1.00	1.54	0.59	0.91	0.84	1.24
ROW	0.03	0.05	0.06	0.07	0.13	0.13	0.05	0.05	0.13	0.12

* in percentage change w.r.t. business-as-usual; ** in percentage; *** in Hicksian EV as % share of business-as-usual GDP

Table B.2: Results on oil market, leakage, and adjustment costs under a reduction target of 10% (*RED-10*) and 30% (*RED-30*)

		EU		EUxUSA		OECD		EUxUSAxCHN		OECDxCHN	
		COM	DOM	COM	DOM	COM	DOM	COM	DOM	COM	DOM
RED-10	Oil market*										
	Crude oil price	-0.30	0.45	-0.61	0.17	-0.89	-0.01	-0.55	-0.09	-0.78	-0.24
	OPEC supply	-0.06	-1.60	-0.19	-1.85	-0.29	-2.15	-0.20	-1.20	-0.28	-1.45
	Non-OPEC supply	-0.20	0.50	-0.49	0.25	-0.78	0.06	-0.46	-0.02	-0.69	-0.17
	Coalition consumption	-1.84	-1.99	-1.49	-1.79	-1.50	-1.84	-1.09	-1.28	-1.09	-1.32
	Non-Coalition consumption	0.27	-0.11	0.40	0.01	0.59	0.13	0.37	0.13	0.53	0.23
	Leakage**										
	Total leakage	15.6	9.5	6.8	4.6	6.2	4.7	3.5	2.8	3.1	2.5
	Coal leakage	7.4	7.8	3.3	3.4	3.4	3.4	1.8	1.9	1.7	1.7
	Gas leakage	3.6	4.3	1.3	1.5	1.1	1.2	0.6	0.7	0.6	0.6
	Oil leakage	4.6	-2.6	2.1	-0.3	1.7	0.1	1.0	0.2	0.8	0.2
	Adjustment costs***										
	Global	0.03	0.05	0.03	0.05	0.05	0.07	0.03	0.04	0.04	0.06
	Coalition	0.06	0.08	0.02	0.04	0.03	0.05	0.02	0.04	0.02	0.04
	OPEC	0.17	0.35	0.26	0.49	0.37	0.65	0.23	0.39	0.32	0.52
	ROW	0.01	0.02	0.02	0.03	0.05	0.05	0.02	0.02	0.05	0.04
RED-30	Oil market*										
	Crude oil price	-1.64	0.84	-3.28	-1.06	-4.77	-2.53	-2.85	-1.64	-4.09	-2.75
	OPEC supply	-0.37	-5.10	-1.11	-5.55	-1.70	-6.25	-1.08	-3.65	-1.57	-4.45
	Non-OPEC supply	-1.20	1.11	-2.87	-0.67	-4.71	-2.36	-2.55	-1.35	-3.99	-2.59
	Coalition consumption	-11.03	-9.95	-8.68	-8.95	-8.93	-9.31	-5.94	-6.29	-6.22	-6.60
	Non-Coalition consumption	1.57	0.19	2.35	1.13	3.49	2.15	2.02	1.32	3.02	2.14
	Leakage**										
	Total leakage	21.8	14.2	9.9	7.6	8.9	7.4	4.9	4.2	4.4	3.9
	Coal leakage	6.9	7.4	3.7	3.8	3.8	3.8	2.0	2.0	1.9	1.9
	Gas leakage	5.6	6.2	2.0	2.2	1.8	1.8	1.0	1.0	1.0	1.0
	Oil leakage	9.2	0.7	4.1	1.7	3.3	1.8	1.9	1.1	1.5	0.9
	Adjustment costs***										
	Global	0.25	0.27	0.28	0.33	0.40	0.46	0.24	0.28	0.34	0.39
	Coalition	0.60	0.54	0.33	0.36	0.37	0.40	0.27	0.29	0.30	0.33
	OPEC	0.90	1.42	1.35	2.07	1.96	2.83	1.16	1.71	1.68	2.37
	ROW	0.06	0.08	0.11	0.13	0.25	0.24	0.09	0.09	0.25	0.22

* in percentage change w.r.t. business-as-usual; ** in percentage; *** in Hicksian EV as % share of business-as-usual GDP

Table B.3: Results on oil market, leakage, and adjustment costs under halved (*ARM_lo*) and doubled (*ARM_hi*) Armington elasticities

		EU		EUxUSA		OECD		EUxUSAxCHN		OECDxCHN	
		COM	DOM	COM	DOM	COM	DOM	COM	DOM	COM	DOM
ARM-LO	Oil market*										
	Crude oil price	-0.97	0.60	-1.79	-0.37	-2.61	-1.07	-1.56	-0.78	-2.21	-1.31
	OPEC supply	-0.16	-3.25	-0.49	-3.40	-0.74	-3.90	-0.48	-2.15	-0.67	-2.60
	Non-OPEC supply	-0.65	0.79	-1.44	-0.09	-2.33	-0.82	-1.31	-0.55	-1.98	-1.10
	Coalition consumption	-4.59	-4.58	-3.62	-4.04	-3.76	-4.23	-2.52	-2.82	-2.64	-2.97
	Non-Coalition consumption	0.55	-0.24	0.74	0.02	1.03	0.22	0.61	0.19	0.83	0.31
	Leakage**										
	Total leakage	16.9	10.3	7.3	5.3	6.4	5.0	3.6	2.9	3.1	2.6
	Coal leakage	6.1	6.7	3.1	3.2	3.1	3.1	1.7	1.7	1.6	1.6
	Gas leakage	4.3	4.9	1.5	1.6	1.2	1.2	0.6	0.7	0.6	0.6
	Oil leakage	6.5	-1.2	2.7	0.5	2.1	0.7	1.2	0.5	0.9	0.4
	Adjustment costs***										
	Global	0.10	0.13	0.11	0.15	0.16	0.20	0.10	0.13	0.14	0.17
	Coalition	0.20	0.21	0.09	0.12	0.11	0.14	0.08	0.10	0.09	0.12
	OPEC	0.55	0.90	0.76	1.21	1.10	1.64	0.66	0.97	0.93	1.33
	ROW	0.04	0.05	0.08	0.09	0.17	0.16	0.07	0.07	0.18	0.16
ARM-HI	Oil market*										
	Crude oil price	-0.61	0.62	-1.43	-0.11	-2.10	-0.66	-1.26	-0.58	-1.80	-1.01
	OPEC supply	-0.18	-2.70	-0.60	-3.35	-0.93	-3.95	-0.59	-2.10	-0.86	-2.60
	Non-OPEC supply	-0.45	0.71	-1.26	0.02	-2.06	-0.62	-1.13	-0.46	-1.74	-0.95
	Coalition consumption	-6.54	-6.27	-5.06	-5.39	-5.04	-5.45	-3.50	-3.75	-3.48	-3.77
	Non-Coalition consumption	1.12	0.41	1.78	1.05	2.72	1.88	1.62	1.22	2.45	1.94
	Leakage**										
	Total leakage	20.9	15.4	9.5	7.6	9.1	7.7	4.9	4.3	4.5	4.0
	Coal leakage	8.5	8.7	4.2	4.1	4.5	4.4	2.3	2.3	2.1	2.1
	Gas leakage	5.5	5.9	2.1	2.2	1.9	1.9	1.1	1.1	1.0	1.0
	Oil leakage	6.9	0.7	3.3	1.2	2.7	1.4	1.6	1.0	1.3	0.8
	Adjustment costs***										
	Global	0.11	0.13	0.12	0.15	0.16	0.21	0.10	0.12	0.14	0.16
	Coalition	0.29	0.29	0.14	0.17	0.16	0.19	0.12	0.14	0.12	0.14
	OPEC	0.34	0.62	0.58	0.99	0.85	1.36	0.49	0.79	0.71	1.09
	ROW	0.02	0.04	0.03	0.05	0.08	0.08	0.01	0.01	0.06	0.05

* in percentage change w.r.t. business-as-usual; ** in percentage; *** in Hicksian EV as % share of business-as-usual GDP

Table B.4: Results on oil market, leakage, and adjustment costs under halved (*FFS_lo*) and doubled (*FFS_hi*) fossil fuel supply elasticities

		EU		EUxUSA		OECD		EUxUSAxCHN		OECDxCHN	
		COM	DOM	COM	DOM	COM	DOM	COM	DOM	COM	DOM
FFS-LO	Oil market*										
	Crude oil price	-1.08	3.83	-2.27	2.81	-3.39	2.52	-2.03	0.92	-2.92	0.60
	OPEC supply	-0.19	-7.10	-0.52	-7.90	-0.82	-9.35	-0.50	-5.05	-0.73	-6.15
	Non-OPEC supply	-0.42	1.80	-1.02	1.39	-1.68	1.23	-0.93	0.52	-1.44	0.35
	Coalition consumption	-5.30	-5.10	-4.05	-5.46	-4.04	-5.81	-2.77	-3.84	-2.76	-4.05
	Non-Coalition consumption	0.86	-1.62	1.38	-1.14	2.08	-0.94	1.21	-0.30	1.79	-0.12
	Leakage**										
	Total leakage	25.3	0.8	11.8	4.9	10.9	6.1	6.2	4.1	5.5	3.9
	Coal leakage	11.1	13.8	5.8	6.1	5.9	6.0	3.4	3.6	3.1	3.2
	Gas leakage	6.5	7.5	2.4	2.8	2.0	2.2	1.1	1.2	1.0	1.1
	Oil leakage	7.6	-20.4	3.7	-4.0	2.9	-2.0	1.7	-0.7	1.3	-0.3
	Adjustment costs***										
	Global	0.11	0.18	0.11	0.22	0.16	0.29	0.10	0.17	0.14	0.22
	Coalition	0.23	0.27	0.10	0.21	0.10	0.23	0.08	0.16	0.08	0.17
	OPEC	0.58	1.08	0.93	1.65	1.39	2.28	0.82	1.35	1.19	1.84
	ROW	0.03	0.09	0.05	0.10	0.14	0.13	0.04	0.06	0.15	0.10
FFS-HI	Oil market*										
	Crude oil price	-0.62	-0.29	-1.15	-0.79	-1.62	-1.20	-0.98	-0.77	-1.37	-1.10
	OPEC supply	-0.10	-1.10	-0.44	-1.55	-0.65	-1.95	-0.46	-1.15	-0.63	-1.50
	Non-OPEC supply	-0.74	-0.16	-1.72	-1.08	-2.77	-2.01	-1.54	-1.15	-2.34	-1.85
	Coalition consumption	-5.27	-5.25	-4.19	-4.29	-4.35	-4.47	-2.98	-3.06	-3.10	-3.20
	Non-Coalition consumption	0.68	0.50	0.91	0.71	1.31	1.06	0.81	0.68	1.17	0.98
	Leakage**										
	Total leakage	14.1	12.7	5.9	5.3	5.2	4.8	2.9	2.7	2.5	2.3
	Coal leakage	5.0	5.0	2.4	2.3	2.4	2.3	1.2	1.2	1.1	1.1
	Gas leakage	3.3	3.5	1.2	1.2	1.0	1.0	0.6	0.6	0.6	0.6
	Oil leakage	5.8	4.2	2.4	1.7	1.8	1.4	1.1	0.9	0.8	0.7
	Adjustment costs***										
	Global	0.11	0.12	0.11	0.13	0.16	0.18	0.10	0.11	0.14	0.15
	Coalition	0.24	0.24	0.12	0.13	0.15	0.16	0.11	0.11	0.12	0.13
	OPEC	0.37	0.52	0.48	0.73	0.68	0.99	0.41	0.60	0.57	0.82
	ROW	0.03	0.04	0.06	0.07	0.13	0.12	0.05	0.05	0.12	0.11

* in percentage change w.r.t. business-as-usual; ** in percentage; *** in Hicksian EV as % share of business-as-usual GDP

Table B.5: Results on oil market, leakage, and adjustment costs under fourfold (*US_4*) and eightfold (*US_8*) supply elasticities for oil and gas in the US

		EU		EUxUSA		OECD		EUxUSAxCHN		OECDxCHN	
		COM	DOM	COM	DOM	COM	DOM	COM	DOM	COM	DOM
US-4	Oil market*										
	Crude oil price	-0.72	-0.06	-1.27	-0.42	-1.93	-0.88	-1.15	-0.59	-1.67	-0.97
	OPEC supply	-0.12	-1.75	-0.37	-2.50	-0.60	-3.20	-0.40	-1.85	-0.58	-2.40
	Non-OPEC supply	-0.70	0.17	-1.75	-0.61	-2.70	-1.30	-1.53	-0.78	-2.27	-1.33
	Coalition consumption	-5.32	-5.27	-4.22	-4.47	-4.34	-4.66	-2.97	-3.18	-3.06	-3.33
	Non-Coalition consumption	0.71	0.36	0.96	0.52	1.44	0.87	0.87	0.56	1.27	0.86
	Leakage**										
	Total leakage	18.0	15.3	7.7	6.5	7.1	6.2	3.9	3.5	3.5	3.1
	Coal leakage	7.2	7.3	3.6	3.6	3.6	3.6	2.0	2.0	1.8	1.8
	Gas leakage	4.6	5.0	1.7	1.7	1.5	1.5	0.8	0.8	0.8	0.8
	Oil leakage	6.2	3.0	2.5	1.2	2.0	1.1	1.2	0.7	0.9	0.5
	Adjustment costs***										
	Global	0.11	0.12	0.11	0.14	0.16	0.19	0.10	0.12	0.14	0.16
	Coalition	0.24	0.24	0.12	0.14	0.14	0.16	0.11	0.12	0.12	0.13
	OPEC	0.42	0.64	0.54	0.88	0.82	1.26	0.48	0.75	0.70	1.05
	ROW	0.03	0.04	0.06	0.07	0.13	0.13	0.05	0.05	0.12	0.11
US-8	Oil market*										
	Crude oil price	-0.63	-0.26	-0.98	-0.27	-1.56	-0.60	-0.92	-0.40	-1.37	-0.68
	OPEC supply	-0.08	-1.20	-0.24	-2.35	-0.43	-3.20	-0.29	-1.90	-0.44	-2.55
	Non-OPEC supply	-0.81	-0.15	-2.06	-0.83	-3.09	-1.47	-1.78	-0.87	-2.59	-1.39
	Coalition consumption	-5.35	-5.32	-4.30	-4.52	-4.45	-4.75	-3.05	-3.25	-3.16	-3.43
	Non-Coalition consumption	0.67	0.47	0.83	0.47	1.28	0.77	0.77	0.49	1.14	0.74
	Leakage**										
	Total leakage	17.7	16.2	7.4	6.4	6.9	6.1	3.8	3.4	3.5	3.1
	Coal leakage	7.2	7.3	3.6	3.6	3.6	3.6	2.0	2.0	1.8	1.8
	Gas leakage	4.6	4.9	1.7	1.8	1.5	1.5	0.8	0.8	0.8	0.8
	Oil leakage	5.8	4.0	2.2	1.0	1.8	0.9	1.1	0.6	0.8	0.5
	Adjustment costs***										
	Global	0.11	0.12	0.12	0.14	0.16	0.19	0.10	0.12	0.14	0.17
	Coalition	0.24	0.24	0.13	0.15	0.15	0.17	0.11	0.13	0.12	0.14
	OPEC	0.39	0.55	0.43	0.76	0.68	1.12	0.39	0.67	0.59	0.96
	ROW	0.03	0.04	0.06	0.07	0.13	0.12	0.05	0.05	0.12	0.10

* in percentage change w.r.t. business-as-usual; ** in percentage; *** in Hicksian EV as % share of business-as-usual GDP

Table B.6: Results on oil market, leakage, and adjustment costs under lower (*EDE_lo*) and higher (*EDE_hi*) global energy demand elasticities

		EU		EUxUSA		OECD		EUxUSAxCHN		OECDxCHN	
		COM	DOM	COM	DOM	COM	DOM	COM	DOM	COM	DOM
EDE-LO	Oil market										
	Crude oil price	-0.63	0.07	-1.28	-0.47	-1.83	-0.88	-0.93	-0.39	-1.36	-0.68
	OPEC supply	-0.06	-1.40	-0.35	-1.95	-0.53	-2.40	-0.28	-1.35	-0.41	-1.75
	Non-OPEC supply	-0.36	0.29	-1.01	-0.23	-1.69	-0.75	-0.72	-0.20	-1.21	-0.56
	Coalition consumption	-4.94	-5.00	-3.64	-3.87	-3.64	-3.91	-2.29	-2.46	-2.30	-2.52
	Non-Coalition consumption	0.88	0.57	1.24	0.88	1.87	1.42	1.17	0.93	1.72	1.39
	Leakage										
	Total leakage	19.5	18.2	8.2	7.6	7.5	7.0	4.3	4.1	3.9	3.7
	Coal leakage	7.7	8.5	3.7	4.0	3.8	4.0	2.1	2.2	2.0	2.0
	Gas leakage	5.0	5.5	1.7	1.9	1.5	1.6	0.9	1.0	0.9	0.9
	Oil leakage	6.8	4.1	2.7	1.7	2.2	1.5	1.3	0.9	1.0	0.7
	Adjustment costs										
	Global	0.11	0.12	0.11	0.14	0.16	0.19	0.11	0.12	0.15	0.17
	Coalition	0.21	0.22	0.12	0.13	0.14	0.16	0.12	0.13	0.13	0.15
	OPEC	0.39	0.54	0.54	0.80	0.77	1.10	0.39	0.57	0.56	0.81
	ROW	0.04	0.05	0.07	0.08	0.15	0.14	0.05	0.05	0.12	0.11
EDE-HI	Oil market										
	Crude oil price	-0.96	1.18	-1.90	0.09	-2.83	-0.59	-1.76	-0.69	-2.50	-1.26
	OPEC supply	-0.25	-4.85	-0.67	-5.15	-1.03	-6.05	-0.69	-3.30	-0.99	-4.00
	Non-OPEC supply	-0.72	1.23	-1.62	0.28	-2.61	-0.41	-1.57	-0.53	-2.34	-1.10
	Coalition consumption	-5.75	-5.08	-4.68	-5.22	-4.82	-5.54	-3.41	-3.89	-3.48	-4.06
	Non-Coalition consumption	0.72	-0.73	1.15	-0.20	1.69	0.12	0.98	0.21	1.41	0.46
	Leakage										
	Total leakage	20.6	0.7	10.1	4.5	9.2	5.3	4.8	3.3	4.2	3.0
	Coal leakage	8.1	4.6	4.3	3.1	4.5	3.6	2.1	2.0	2.0	1.8
	Gas leakage	5.1	4.7	2.0	1.9	1.7	1.6	0.9	0.9	0.9	0.8
	Oil leakage	7.4	-8.6	3.7	-0.5	3.0	0.2	1.8	0.5	1.4	0.4
	Adjustment costs										
	Global	0.11	0.14	0.11	0.16	0.16	0.22	0.09	0.13	0.12	0.17
	Coalition	0.26	0.24	0.11	0.15	0.12	0.16	0.08	0.11	0.08	0.12
	OPEC	0.50	1.01	0.78	1.43	1.17	1.95	0.72	1.18	1.03	1.60
	ROW	0.02	0.05	0.04	0.06	0.12	0.11	0.04	0.05	0.13	0.11

* in percentage change w.r.t. business-as-usual; ** in percentage; *** in Hicksian EV as % share of business-as-usual GDP