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Demand Side versus Supply Side Climate Policies

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Abstract

So far discussion and implementation of climate policies has predominantly aimed at reducing consumption of fossil fuels through demand-side climate policies, for example, under the European Union Emission Trading System (EU ETS). However, a country that produces and consumes fossil fuels can also pursue supply-side policies (constraining production of fossil fuels) as well. The net global effect on GHG emissions of the two different actions depend on the elasticities of demand and supply of fossil fuels. This thesis discusses unilateral actions for contributing to climate change mitigation by limiting own oil extraction. I answer the question, does supply side climate measures belong in the optimal mix? Using field specific data on costs, production, number of wellbores, reservoir depth, water depth and oil prices on 17 oilfields on the Norwegian continental shelf I explore analytically the case of Norway's unilateral action of limiting oil extraction. The results of the panel data analysis supports previous studies, reveals that supply-side policies belong in the optimal mix and it is cost effective for Norway to pursue a combination of demand side and supply side climate measures than a standalone demand or supply side policies.

Acknowledgement

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Special thanks to my wife Lucy for her encouragement and moral support. My appreciation to colleagues and dear friends for standing by my side. Finally, glory be to my Lord and God Jesus Christ for his grace.

Any errors are the sole responsibility of the author.

Munyaka Mutua

Ås, September 14, 2019

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1 Introduction

1.1 Short background and main problem statement

There is compelling scientific evidence that the observed increase in global average temperatures is due to anthropogenic greenhouse gas emissions (GHGs) (IPCC, 2014). Carbon emissions generate severe global climate damages; thus, mitigation necessitates global cooperation. For many decades, efforts towards global cooperation in international climate negotiations have made little progress, and prospects for full cooperation have looked bleak (Eichner & Pethig, 2015). Therefore, the COP21 was a step in the right direction, and the Paris Agreement is hailed as the most important achievement in global climate change negotiations. Yet, in its current form, it is difficult to regard the agreement as binding given the vaguely formulated targets of many countries. According to Fæhn et al. (2018), many of the Intended Nationally Determined Contributions (INDCs) will be more than met even without any mitigation efforts. This highlights the challenge in achieving climate agreements that lead to reduced emissions needed to halt climate change.

Norway, as is the case for UK and Denmark, exports fossil fuels to other European countries. When this fuel undergoes combustion, it contributes to GHG emissions. On the other hand, European countries have some of the most ambitious climate targets for GHGs. For instance, Norway, under the Kyoto protocol has committed to reduce GHGs by the equivalent of 30% of its own 1990 emissions by 2020 Fæhn et al. (2018); (Ministry of Climate and Environment, 2016-2017). While this is an ambitious target, Norway has not considered supply side policies to complement demand side measures in its policy mix to meet these targets.

The current discussion and implementation of climate policies predominantly focuses on curbing the consumption of fossil fuels through demand-side climate policies, for example, under the European Union Emission Trading System (EU ETS). However, at least theoretically, supply-side policies (regulating production of fossil fuels) could work as well. This thesis investigates unilateral climate policies; demand side versus supply side policies. Since there is vast literature on the demand side measures, I have chosen to investigate supply side measures, and rely on existing research on demand side to argue if supply side measures belong in an optimal mix. The research seeks to answer the following question: Given Norway's 2020 domestic target for emission reduction, is it cost effective for Norway to pursue a standalone demand-side or supply side policy or is a combination of demand and supply side policy better?

1.2 Hypothesis

In theory when the price elasticity of demand is high relative to the price elasticity of supply, leakage rates are higher under demand side climate policies compared to supply side policies. Thus, it is expected that supply side policies will at least theoretically do better than demand side policies. A logical step here is that supply side policies (as they are expected to be less costly) belong in an optimal mix. One way of depicting this is in a bathtub diagram Fig.1.

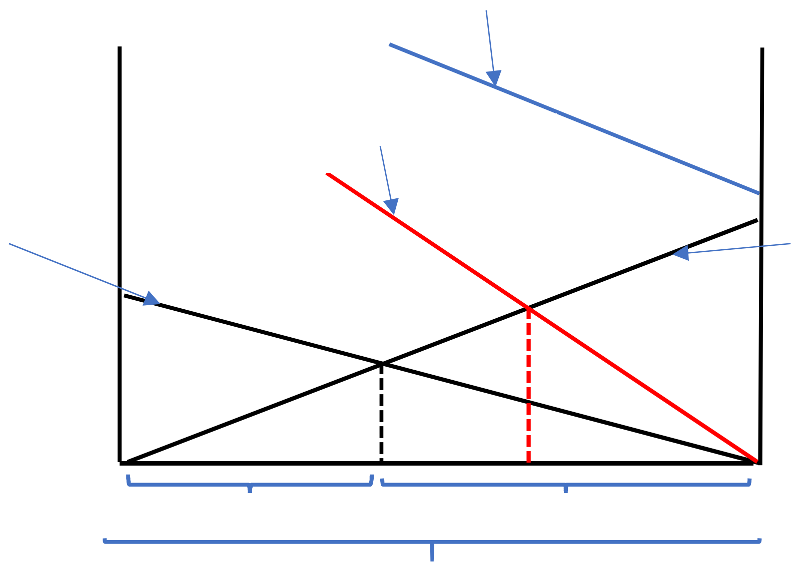

Figure 1:1, Supply side measures belong in an optimal mix

It shows that if supply side measures are the cheapest, (low cost MC) then most emission reduction measures should come from supply side, however, if supply side measures are the costly (high cost MC), then demand side measures should contribute more towards emission reductions. The only perceivable scenario where supply side measures will not form part of an optimal mix is when such measures are associated with super high costs. Norway's emission reduction targets in such a scenario are fully covered by demand side measures at a cost lower than supply side measures. However, this is an unlikely scenario, and under the current policy options for Norway, demand side measures are not sufficient to meet Norway's emission reduction targets by 2020. I thus seek to test the hypothesis whether incorporating supply side measures to Norway's 2020 demand side emission reduction measures will lead to higher emission reductions at a lower cost.

1.3 Structure of the Thesis

The rest of the thesis is structured as follows, Section 2 provides background information and literature review while Section 3 maps out economic theory relevant to the thesis. In Section 4 I present data and methodology. Results and discussion will be presented in Section 5. Section 6 concludes the thesis.

2 Background and Literature Review

2.1 The Current Picture

Fossil fuel combustion contributes the largest share of anthropogenic greenhouse gas emissions (GHGs), releasing over 30 billion tonnes of CO_2 yearly into the atmosphere. Thus, curbing fossil fuel combustion has emerged as a dominant agenda item in climate policies. Current efforts on slowing the consumption of fossil fuels focus on demand side measures such as carbon taxes and emissions trading systems (ETS), energy efficiency standards and incentives for zero-emissions power (Lazarus et al., 2015). Demand side policies reduce emissions by providing incentives to lower the use of fossil fuels, coal and other energy intensive consumption. For decades, global and national climate policies have primarily focused on demand side policies. This focus has led to important policy accomplishments like widespread adoption of carbon pricing initiatives, but possibly at the extent of missing some low-cost supply measures that could belong to the optimal set of policies.

As of 2018, 45 national and 25 subnational jurisdictions had carbon pricing initiative implemented or scheduled for implementation World Bank (2018). However, despite their wide spread adoption across jurisdictions, demand side policies are yet to put fossil fuel consumption on a trajectory consistent with keeping global warming below the 2°C scenario (Lazarus et al., 2015; Rogelj et al., 2018).

The carbon budget available to keep us in a path consistent with the 2°C target is limited. To meet the goals of the Paris agreement much of the world's existing oil, gas and coal reserves must remain on the ground (McGlade & Ekins, 2015). To increase the probability of limiting global warming to less than 2°C, it is necessary with a rapid phase-out of fossil fuels use over the coming years. Norway and many other nations have focused on demand side policies to reduce the demand for fossil fuels, but these measures have been inadequate to stop the rise in global GHGs. However, at least theoretically, supply-side policies (regulating production of fossil fuels) could work as well. Incorporating supply side measures to restrict fossil fuel supply will complement demand-side measures and help fast-track the progress towards the 2°C goal (Fæhn et al., 2014).

In a unified world, with a global climate agreement, demand side policies versus supply side policies would in theory yield the same effect on global emissions. At the global level extraction must equal consumption. Thus, a cap on fossil fuel consumption would result in same effects as a cap on fossil energy production. Assuming fossil fuel markets were perfect, the costs would also be equal Fæhn et al. (2014).

However, we do not have a global government, and global cooperation in reducing climate change appears hard to actualize as shown in the withdrawal of the United States of America from the Paris Agreement, an agreement it had ratified. In a second-best situation, a country or a sub-global coalition unilaterally may restrict domestic demand for fossil fuels or reduce own supply for fossil fuels. It is therefore valid to examine if supply side policies belong in an optimal mix.

2.2 Regulatory Framework

2.2.1 The Paris Agreement

In December 2015, at COP 21 in Paris, parties to the United Nations Framework Convention for Climate Change (UNFCCC) reached a landmark agreement to combat climate change by reducing greenhouse gas emissions (GHGs) (United Nations Framework Convention on Climate Change, 2018.10.22). The adoption of the Paris agreement marked a turning point in international climate cooperation. The agreement enjoys wide global support despite the announcement by the United States of America to withdraw. The European Union and China have given high priority to its implementation. Norway ratified the agreement on 20th June 2016. The agreement brings all nations into a common cause to enhance global response to the threat of climate change. It sets out a global action plan that puts the world on a trajectory to avoid disastrous climate change by limiting global warming to well below 2°C above pre-industrial levels, and pursuing efforts to limit the temperature increase to 1.5°C.

The Paris Agreement is set to apply after the second commitment period under the Kyoto protocol which ends in 2020.(Ministry of Climate and Environment, 2016-2017) It establishes the legally binding obligations and the policy guiding framework. The Paris agreement applies to all signatories of the agreement (hereafter the Parties). However, the pre-1990 industrialized countries bear most of the mitigation costs. All Parties must submit their best efforts to cut GHGs emissions through nationally determined contributions (NDCs). It also involves mandatory emissions reporting where all Parties are required to report regularly their emissions and implementation measures. In addition, there will be a regular global stock-take of collective progress. Norway, in a common goal with EU, have committed to a 40% reduction by 2030 compared to their 1990 emissions levels.

In the Kyoto Protocol, the distribution of the burden emerged from negotiations, and countries aimed at a common ambition. A point of departure in the Paris Agreement is that in the new agreement, each country decides which contributions to communicate and the level of ambition for its Intended Nationally Determined Contributions (INDCs). Basing the Paris Agreement on nationally determined emissions reduction contributions formed the corner stone for its success. This ensured the Paris Agreement was broad and deep, covering virtually 96% of the global emissions (Fæhn et al., 2018). Broad participation in the agreement is important. Without it the agreement is susceptible to carbon leakage i.e. emissions reductions in the countries participating in the agreement are partly offset by emissions increase among free riders (countries not part of the cooperation and without binding emissions caps).

2.2.2 Norwegian climate policy

Norway's climate target is deemed highly ambitious, and is spread out across policy documents, namely:

a) The updated cross-party agreements on climate policy from 2012 (published as a recommendation to the Storting (Innst. 390 S (2011–2012)) in response to the white paper on Norwegian climate policy (Meld. St. 21 (2011–2012));
b) The white paper New emissions commitment for Norway for 2030 – towards joint fulfilment with the EU (Meld. St. 13 (2014–2015)) and a subsequent recommendation to the Storting (Innst. 211 S (2014–2015));
c) The documents relating to the Storting's consent to ratification of the Paris Agreement (Innst. 407 S (2015– 2016) and Prop. 115 S (2015–2016)) and
d) The Climate Change Act adopted by the parliament in June 2017.

Norway's climate targets are;

a) A commitment that Norway will reduce GHGs by the equivalent of 30 % of Norway's own 1990 emissions by 2020.
b) Norway will reduce emissions by at least 40% by 2030 compared with 1990 levels
c) To be climate neutral by 2030
d) Low emissions society by 2050

The target to be a low emissions society by 2050 was entrenched in the new Climate Change Act adopted by Parliament in June 2017. An important implication of this is that the Climate Change Act target of 40% emissions reductions by 2030 becomes legally binding. The 2030 target of 40% is also Norway's contribution under the Paris agreement, and it has been communicated to the UNFCCC. Notably missing in the new act is the 30% target for 2020. This is covered in the second commitment period of the Kyoto Protocol. This period runs from 2013 to 2020, after which the Paris agreement starts (Ministry of Climate and Environment, 2016-2017).

2.2.3 EU climate policy

The EU has set a target to cut its overall GHG emissions by at least 40% from 1990 to 2030. The EU's climate policy is anchored on three pieces of legislation;

1) The Emissions Trading System (EU ETS). Emissions from petroleum industry, aviation, industrial plants, and power plants are covered under the EU ETS. Through the ETS, the EU has set a target of 43% reduction of emissions by 2030 compared with EU's emissions 2005.
2) The proposed Effort Sharing Regulation (ESR). This covers non-ETS emissions, i.e. emissions from the petroleum and manufacturing sectors, emissions from transport, agriculture, buildings, and waste management. Through the ESR the EU has proposed a 30% cut in emissions by 2030 compared with own emissions 2005.
3) The proposed Land Use, and Land Use Change and Forestry (LULUCF) regulation. The target under LULUCF is that individual states policies need to ensure that recorded emissions in the sector do not exceed the recorded removals of CO_2. This is also referred to as the no debit rule.

Norway has participated in the EU ETS from 2008 and is therefore subject to the same terms as the EU member countries.

2.3 Emissions from the petroleum sector

The Petroleum sector activities, transport and industry account for the largest share in Norway's domestic emissions. In 2017, the petroleum sector GHG emissions amounted to about 13.6 million tonnes CO_2 eq. (carbon dioxide equivalent) as shown in figure 2:2,

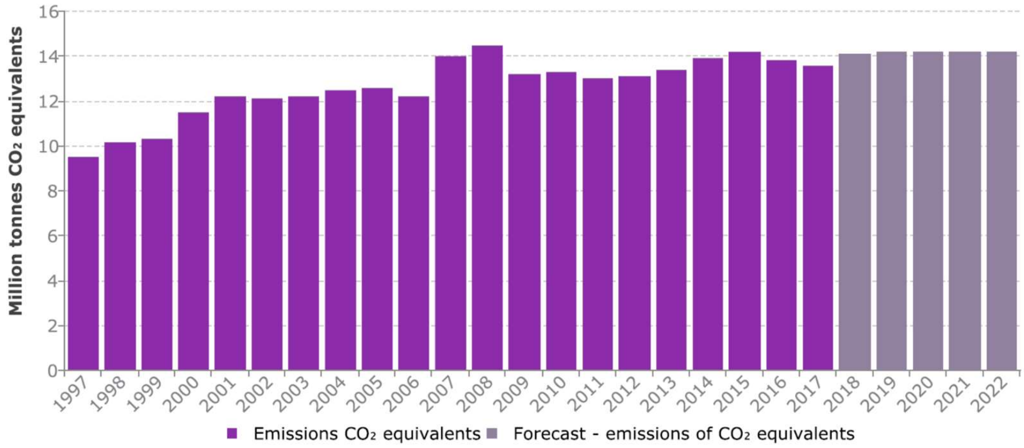

Figure 2:1, Historical GHG emissions & projections Source: NPD 2019

Emissions from the sector constituted about 25% of Norway's aggregate GHG emissions. (Norwegian Petroleum, 2018.06.20). The emissions from the petroleum sector largely originate from the combustion of natural gas and diesel in the turbines, engines and boilers that keep the facilities operational (Figure 2:4).

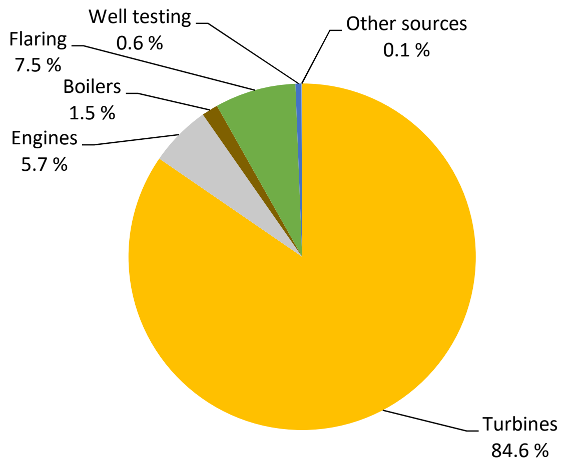

Figure 2:2: CO_2 emissions from petroleum activities 2017, by source. Source: NPD 2019

Additional sources of CO_2 emissions include; flaring of natural gas for safety measures, ventilating and diffuse gas emissions from storage and loading of crude oil.

Since 1990, Norway has experienced economic growth generating a general growth in emissions. Norway's offshore petroleum sector has expanded significantly for the past 20 years. This has resulted in higher CO_2 emissions from energy use, both in energy industries and transport (Figure 2:5).

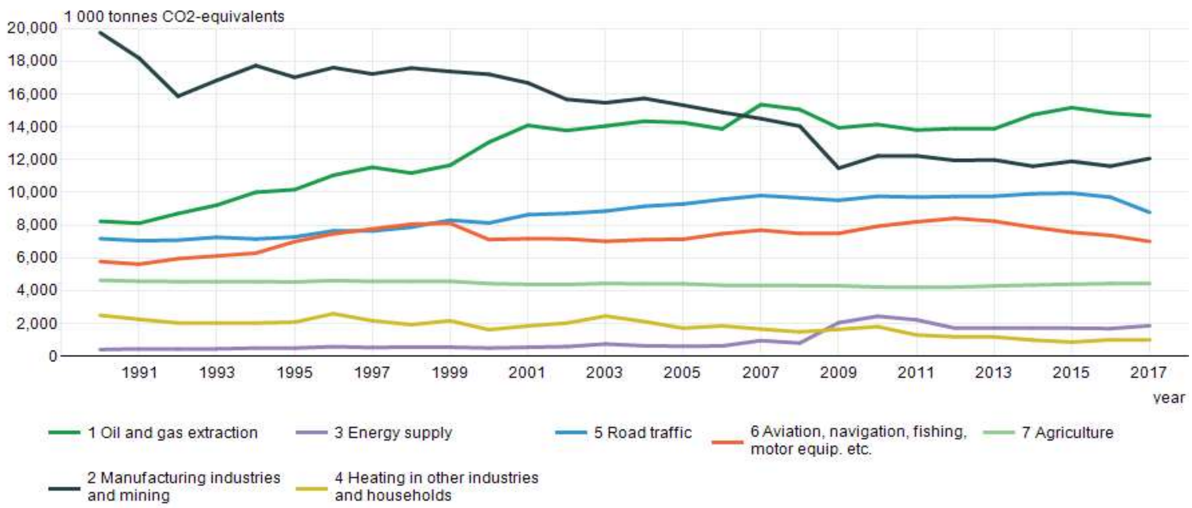

Figure 2:3: GHG emissions by source. Statistics Norway 2019.

2.4 Current instruments regulating the Petroleum Sector

The Greenhouse Gas Emissions Trading Act and the CO_2 tax on Emissions constitute the policy instruments regulating the Norwegian petroleum sector. Though both the carbon tax and the EU ETS apply to the petroleum sector, most sectors take part either in the EU ETS or pay the carbon tax.

2.4.1 Carbon tax

Norway, affirming her position as a pioneer in climate change policies introduced the carbon tax in 1991. As is the case for many other EU countries, the Norwegian carbon taxes are highly differentiated between sectors. This implies that the average CO_2 tax varies within sectors, subject to the diversity of the taxation rates, utilization of fossil commodities and use of those commodities. (Bruvoll & Dalen, 2009). Given the correlation between use of fossil fuels and emissions, the CO_2 taxes are levied at the production stage. The tax is determined by the Ministry of Finance and is levied on all combustion of gas, oil and diesel in petroleum operations on the continental shelf and on releases of CO2 and natural gas, in accordance with the CO2 Tax Act on Petroleum activities. The tax rate for 2019, is NOK 1.08 per standard cubic metre of gas or per litre of oil or condensate.

This translates to NOK 462 per tonne of CO_2 for combustion of natural gas. The tax rate is NOK 7.41 per standard cubic metre for emissions of natural gas (Norwegian Petroleum, 2018.06.20).

2.4.2 Greenhouse Gas Emissions Trading

Norway's Greenhouse Gas Emissions Trading Act entered into force in 2005, while participation in the EU ETS started in 2008. Since then, Norwegian installations in the petroleum industry and other industries to which the system applies are subject to the same rules as other EU members. About 50% of Norway's emissions are covered under the EU ETS, of which the petroleum and manufacturing activities constitute larges shares. The EU ETS is currently in its third phase, which runs up to the end of 2020.

The EU ETS is a cap and trade system sets an overall limit or cap, on total GHGs within the system. Any tradeable cap and trade system implicitly creates a new type of property right, called a permit or allowance. A tradable permit or allowance is a widely accepted instrument, and it gives firms the right to emit a specified number of units of emissions. Emissions allowances are allocated by auctioning or issued free of charge e.g. grandfathered. The EU ETS issues allowances for free to sectors considered to be at risk of carbon leakage, this includes some petroleum sector emissions. Allowances for emissions from heating and electricity generation on offshore installations are not allocated free of charge.

Once a company has exhausted its free allocation, it must purchase extra allowances from other companies in the system. Companies with surplus allowances can sell them to the ones who exceed their free allowances. The ETS provides incentives for cost-effective cuts in greenhouse gas emissions. In 2018, an emission allowance averaged NOK 155 (about 16.12 Euros). This would entitle the permit holder to emit one tonne of CO2.

Following the combination of the carbon tax and the EU ETS, companies operating on the Norwegian shelf are subject to higher payments per tonne of CO_2 (about NOK 700 per tonne of CO2 emitted) compared to other businesses in Norway, and much higher compared to other petroleum producing countries. Emissions per unit of oil and gas produced are therefore generally lower for Norwegian companies.

Though the EU is on track to achieve the 2020 climate goal of a 20% reduction in own emissions compared to 1990 level, there has been a general concern about its impact. The large surplus of allowances in early stages of the system resulted in low prices of emission allowances.

Tradeable permits offer strong incentives for R&D; however, low carbon prices render the EU ETS less effective in promoting R&D. One way to increase the price would be to tighten the cap. Tightening the cap reduces the excess allowances and rises the carbon prices. Even though Norway has argued for a tighter cap, this proposal has not received political backing within the EU. In its place technical measures like the establishment of a market stability reserve have been introduced.

This will remove surplus emission allowances temporarily from circulation, and fewer allowances will be available to installations in the system. In the long run, the continuous reductions in emission allowances available implies the ETS will bring about substantial cuts in emissions.

2.5 Literature Review

A key decision in climate policy is the choice of pollution control instruments to pursue. These instruments can be broadly classified under two categories; demand side policies or Supply side policies. A country or coalition that seeks to cut emissions, can opt for demand side or supply side policies, or a combination of both policies. Economists and policy makers have focused greatly on policy instruments that restrict demand for GHGs. Market based instruments especially "cap and trade" schemes and carbon taxes have been preferred as they seem to perform better than alternatives against economists favoured criteria of economic efficiency and cost effectiveness (Goulder & Parry, 2008). Such instruments have been implemented in many countries across the globe and are scheduled to be implemented in many more countries. According to Stavins (2003), under the right conditions, market based instruments for carbon pricing are at least theoretically the most cost effective policy instruments in abating pollution. Carbon taxes and emission trading systems are driving more abatement at lower cost compared to other pollution abatement instruments (OECD, 2013). However, the ability of these instruments to bring about long-term transformation can be greatly undermined by design and implementation (Collins & Mendelevitch, 2015). A case at hand is the EU ETS, which has generated low carbon prices mainly due to generous allocation of free allowances in the past, in particular in 2005-6 where the quota price was zero. This has greatly impacted on the effectiveness of the EU ETS. On the other hand, higher prices are needed to drive investment from dirty to green energy.

Domestic Policy measures for reducing fossil fuel demand lead to lower international energy prices and may reduce the competitiveness of domestic firms in the world markets for energy-intensive goods.
Both channels i.e. the international energy markets and emissions intensive industries are channels for carbon leakage. Thus, in the absence of a joint global climate policy, demand-side policies are susceptible to carbon leakage, i.e. emissions reductions in home country or the participating countries are partly offset by emissions increase among free riders (Hoel, 2013). Carbon leakage undermines abatement efforts of a country or coalition implementing climate policies. There is a vast literature on carbon leakages, and most studies on this issue suggest a leakage rate of 5% to 30% (Böhringer et al., 2012; Hagem & Storr∅ sten, 2019; Zhang, 2012). However, Babiker (2005) who criticizes overly simplistic assumptions on market and industry structure, reports leakage rates over 100%, suggesting a significant relocation of energy intensive industries from the OECD countries.

A further concern with demand side policies is the 'green paradox'. The green paradox is an undesirable effect of an environmental policy. If resource owners feel threatened by an environmentally friendly policy that will destroy their business (like depress the price of carbon), resource owners may react by accelerating their present rate of extraction in order to maximize the net present value of their resource rents. Within such a perspective, demand side policies designed to depress the world price of carbon (like a fast-increasing carbon tax or a subsidy on renewables), resource owners may see such policies as a threat to future extraction. The risk of a future higher carbon price reducing the current value of fossil fuel resources provides an incentive to resource owners to accelerate resource extraction reducing its market price. The lower prices translate to an increase in consumption. Faster extraction of the resource leads to increase in global emissions in the short term, and accelerates global warming (Sinn, 2008). There is a large literature following up on this phenomenon since Sinn's seminal paper on the Green Paradox see (Hoel, 2010; Jensen et al., 2015; Ritter & Schopf, 2014; Van der Ploeg & Withagen, 2012).

Supply-side policies are supposed to mitigate the impacts of the Green Paradox, and to counteract the issue of carbon leakage. Bohm (1993), suggests that countries should focus on supply side policies to avoid carbon leakage. Lower supply of fossil fuels will cause the prices to rise and lead to a lower consumption among the free riders.

Hoel (1994), in a static model, derived the (second best) optimal combination of producer and consumer taxes in a climate coalition given a target for global emissions, the tax rate being determined by the demand and supply elasticity and term-of-trade effects.

Similarly in a static framework, Golombek et al. (1995) and Fæhn et al. (2014) show numerically the optimal combination of demand-side versus supply-side policies. Harstad (2012) argues that leakage is a problem that can be avoided. His intuition is that a coalition implementing climate policies can buy marginal foreign fuel deposits in non-cooperative countries and conserve them. While this is a promising result, purchasing foreign deposits is a challenging proposition faced with asymmetric information, contract incompleteness, bargaining failure, and political problems.

According to Collier and Venables (2014) carbon leakage under supply side policies is minimized compared to demand side policies when the price elasticity for demand is high relative to the price elasticity of supply. Hoel (2012) looks at supply side policies and states that the threat of green paradox can be eliminated through properly designed supply-side policies. He shows that conserving the marginal resources reduce both total and immediate resource extraction. Venables (2011) argues that while decreasing prices may cause resource owners to extract more in earlier time periods, this effect is offset by resource owners postponing effect on field opening following the anticipation of stringent climate policies.

Reducing emissions from fossil fuels consumption is necessary for meeting the 2°C target. This may be pursued through policies that act to reduce the demand for fossil fuels or policies that restrict the supply of fossil fuels. The optimal choice of policies for different countries will need to be tailored to national circumstances and political feasibility of implementation. In the absence of global cooperation supply side policies seem to do better, or at least complement, demand side policies.

3 Economic Review

3.1 Norwegian Oil Extraction and Global Emissions

In Norway the Ministry of Petroleum and Energy oversees the issuance of production licences. These licences grant the right to explore, drill, and extract petroleum within the area covered by the licence. The Norwegian parliament, Stortinget, decides which fields to open. However, the decision on how much to extract is made by the licensees (Fæhn et al., 2018). In a perfect market model, the market would induce licensees to extract oil in a profit maximising behaviour. Reserves with the lowest marginal extraction costs are tapped first followed by reserves with higher marginal costs (Holahan & Kroncke, 2004). Extraction continues until marginal cost rises to price. Reserves that cannot be extracted profitably at current prices are left in the ground. These reserves are available for future extraction should prices rise, or a technological change that reduces extraction costs. Hence, the decision to extract oil depends on the comparison between expected marginal costs and expected price. A profit maximising firm will select its output to set marginal cost equal to price. Figure 3:1, illustrates a simple two-period model without technological progress, i.e., marginal costs are not lowered over time.

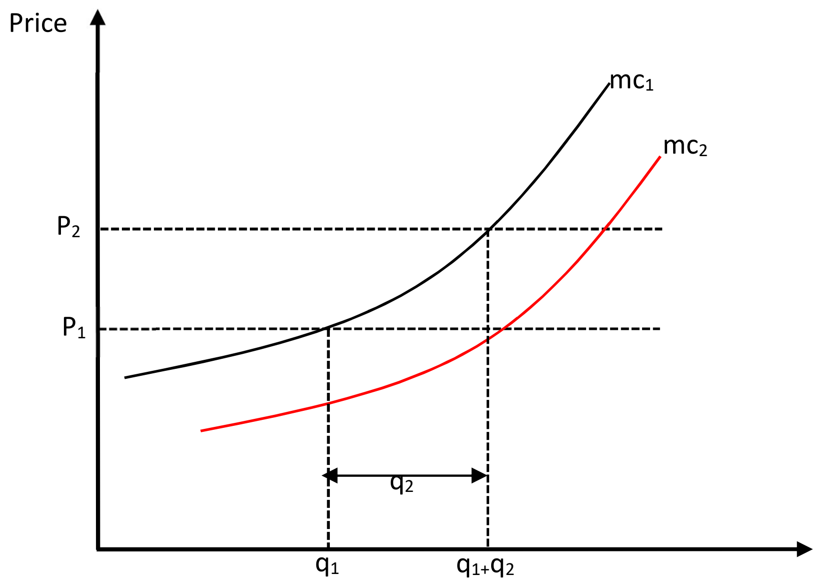

Figure 3:1 Economics of oil extraction

In Figure 3:1, q_1 is mined in period one at the exogenously given price p_1, and $q_2 = q_1 + q_2 - q_1$, is mined in period two at the exogenous price p_2. Technological progress usually manifests itself through a downward movement of the marginal cost curve, indicated by the red curve MC_2.

This leaves the oil mining company with the decision of mining a bit less in time period one to get the benefits of the lower mining costs in period two. Figure 3:2, provides an illustration where it is assumed profitable to move some of the mining from period one to period two, i.e. q'_1. i.e., less than q_1.

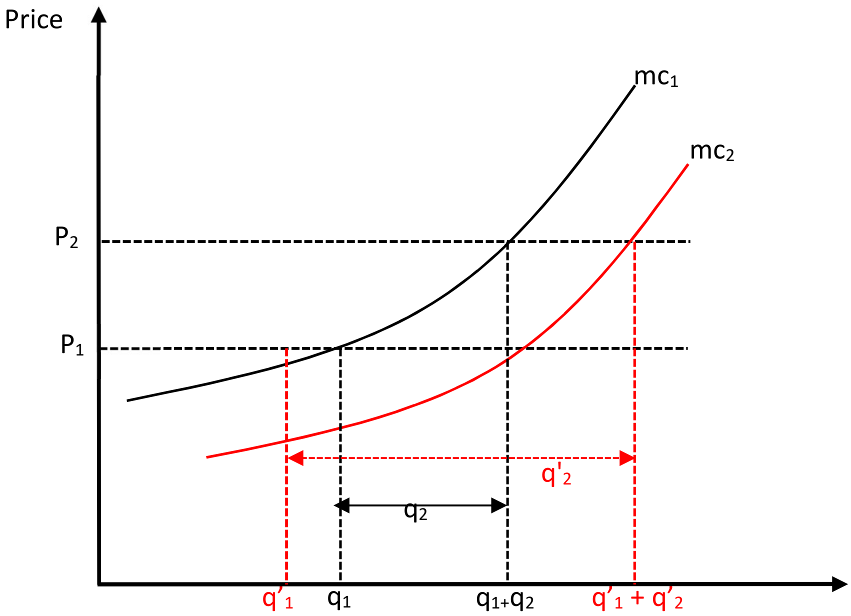

Figure 3:2 Economics of oil extraction

From Hotelling's (1931) seminal paper that the optimal mining in this case is such that the rents, π, from mining should follow the equation $\pi_2 = \pi_1 e^{rt}$, where r is the discount rate, π_2 is the resource net price in period 2, π_1 is the initial net resource price (at period 1).

Figure 3:3, presents a stylized version of the impact of environmental policies limiting oil production.

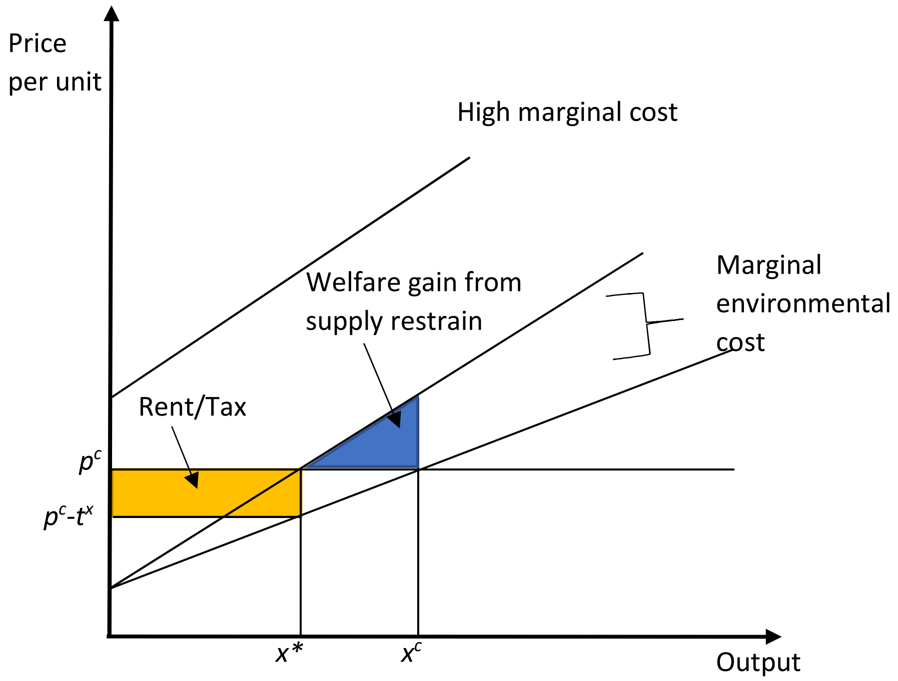

Figure 3:3 the impact of environmental policies limiting oil production

When environmental risks are ignored, a profit maximising firm will produce at the competitive level x^c where the firm's private marginal cost equals the market price p^c, which the firm treats as exogenously given. In the first best, environmental costs are incorporated in the extraction decision, resulting in lower extraction. The efficient production is now at a lower level x^*, where supply and environmental costs equal p^c which can be induced by a unit production tax. When firms consider the social cost of carbon, there are economic welfare gains, represented by the blue triangle. The high marginal cost curve shows a case where the environmental costs are extremely high. There should be no extraction in such a field. A good example is oil fields Nordland VI, Nordland VII, and Tromso II. Opening the areas outside Loften, Vesterålen and Senja for petroleum activities will lead to natural interventions in one of the world's most vulnerable sea areas, which is home to important spawning grounds for fish.

3.2 Emissions reductions from constraining oil production

When oil is extracted, each barrel of oil contains carbon that once refined into products and burned, releases at least 400 kg CO_2 (Erickson et al., 2018). On the average, emissions associated with extracting one tonne of Norwegian oil is about 60 kg CO_2 (Gavenas et al., 2015).

Notably, the emission intensity for Norwegian oil and gas extraction is below the world average, which amounts to about 130 kg CO_2. One reason given by the Ministry of Petroleum and Energy(2018) is that the companies operating on the Norwegian shelf are subject to the Norwegian carbon tax and the EU ETS. Market based instruments like the Norwegian carbon tax and the EU ETS provide households and companies incentives to undertake adjustments such as abstaining from an activity, fuel switching or choosing a more energy- or carbon-efficient solution. Thus, the Norwegian carbon tax, and the EU ETS have led to use of solutions that reduce and prevent greenhouse gas emissions. Emissions per unit of oil and gas produced are therefore lower than emissions from similar operations in other petroleum-producing countries with less stringent climate policies. However, the direct effect of reducing Norwegian oil extraction is counteracted by different responses in energy markets.
Restricting fossil fuel production is rooted in the economic theory that countries who undertake unilateral action to curb CO_2 emissions can enhance their effectiveness by also cutting fossil fuel production. A constraint on fossil fuel production increases prices and reduces fossil fuel consumption. This will result in reduced CO_2 emissions. Carbon leakage across borders can be used to illustrate this. I use Figure 3:4, to illustrate in a simplified manner the effects of a supply cut in the oil market.

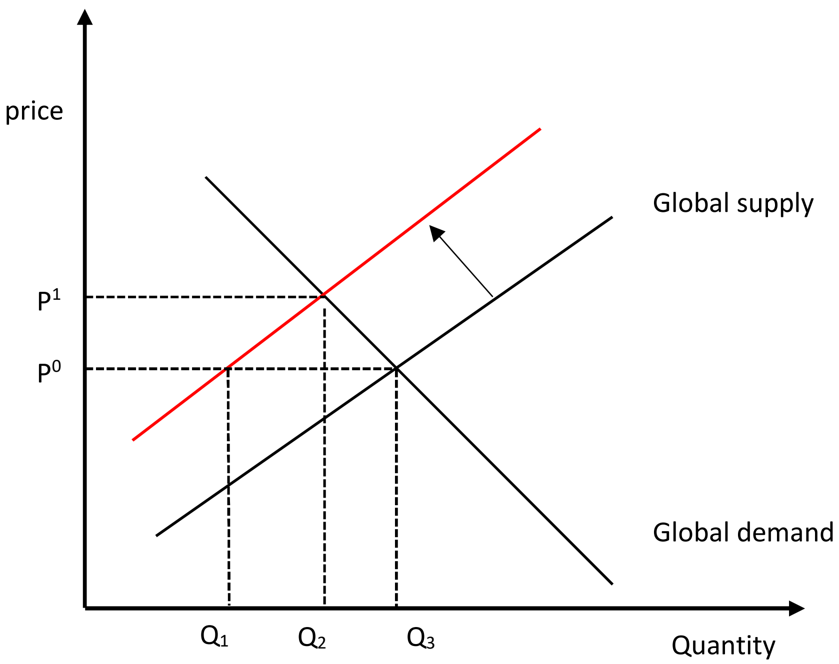

Figure 3:4 impacts of a supply cut on the oil market

The initial equilibrium is at the point where global demand and global supply intersect. The corresponding global consumption is at point Q_3. When Norway implements a supply cut, the global supply shifts inwards.

The supply reduction is the difference between Q_3 and Q_1. A lower supply results in a higher price (from P^0 to P^1), which also triggers increased supply from other countries equivalent to (the difference between Q_2 and Q_1, which is the leakage effect). Global consumption also goes down and corresponds to point Q_2 in the figure. The net effect on global oil consumption is a reduction from Q_3 to Q_2.

If the slope of the demand curve equals the slope of the supply curve, then the change in oil consumption Q_3 to Q_2 is equal to half the original cut, Q_3-Q_1.

Thus, a key determinant of the magnitude of leakage is the relative elasticities of supply and demand. Therefore, elasticities of supply and demand provide a framework for understanding the effectiveness of supply-side climate policies.

3.3 Price elasticity of supply and demand

Price elasticities are quite useful and important factors for policy design. Leakage undermines the effectiveness of both demand- and supply-side policies. The indirect effects lead to CO_2 emissions increasing abroad. For countries considering unilateral climate policies, leakage associated with fuel price effects will be an important factor in determining policy effectiveness. In Figure 3:5 below, simple supply and demand curves and their associated price elasticities are used to assess the magnitude of leakage.

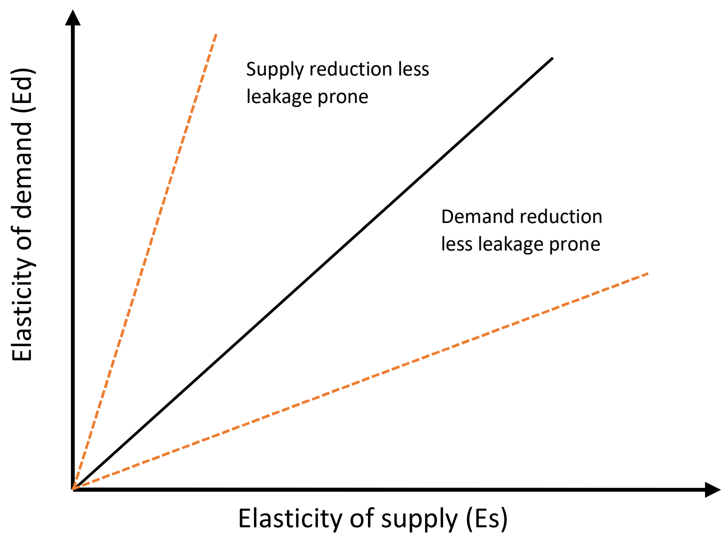

Figure 3:5 the leakage effects of supply or demand side measures

As shown in Figure 3:5, where the price elasticity of demand is more elastic than the price elasticity of supply, the leakage rate will be greater for demand side policies, on the other hand where the price elasticity of supply is more elastic than the price elasticity of demand, the leakage will be greater on the supply side policies.(Harstad, 2012) (Collier & Venables, 2014).

On the top left of Figure 3:5, demand is more elastic than supply, leakage will be greater for demand side climate policies than for supply side measures. As we move to the bottom right, the converse is true, i.e. supply leakage is greater and demand side measures become less prone to leakage. A very elastic supply implies that a small price increase triggers a large increase in global supply. If this happens, the supply-side leakages will be large. Therefore, the effectiveness of a cut in fossil fuel supply will depend on the ability of fossil fuel producers to respond to price increases. If fossil fuel producers are not able to increase extraction in response to a price increase i.e., low elasticity of supply, a cut in fossil fuel will be more effective in curbing emissions. Conversely, an elastic demand curve means that a negative supply shift results in a small price increase. Hence, other fossil fuel producers have weak incentives to increase supply, implying low leakage (Holtsmark, 2019).

3.4 Carbon leakage

Carbon leakage is an issue that must be included in a supplemental policy that aims to combat carbon emissions. As noted above carbon leakage occurs when climate policy in one country leads to increased emissions in other countries. For instance, GHGs and unilateral action creates carbon leakage and stems from activities such as the relocation of emission-intensive and trade-exposed output (production) to countries with loose (or less strict) regulations (Böhringer et al., 2017). Our discussion has focused on leakage through international energy markets like oil and coal. Carbon leakage also occurs through other channels like international markets for emission intensive goods such as steel and cement (Zhang, 2012). Moreover, firms that are subject to strict climate policy can relocate to other countries. Similar mechanisms are also in play on the demand side.

Hoel (1994) develops a theoretical framework that shows different ways of determining the trade-off between supply and demand side measures. One way is to focus on the cost of reducing demand and supply respectively. The other is the magnitude of carbon leakage on both sides. As noted earlier this depends on the associated elasticities. In a relatively elastic supply curve compared to demand curve, supply side leakage is greater than demand side leakage. This pushes the optimal combination of supply and demand side climate policies towards more emissions reduction on the demand side.

So how can we measure leakage? The leakage rate is calculated as follows:

$$LR = \frac{\Delta(Foreign\ emissions)}{-\Delta(Domestic\ emissions)} * 100\%$$

Where the leakage rate is equal to the change in foreign emissions, divided by the negative change in domestic emissions and is expressed in percentage terms. Ultimately, carbon leakage reduces the benefits of climate policy.

The literature on this topic suggests that there is a way to mitigate carbon leakage through anti-leakage measures such as border carbon adjustments (BCA), or output-based allocation (OBA). Böhringer et al. (2017) suggest the latter, a policy mix of output-based allocation combined with a tax on consumption. An output-based allocation functions like a production subsidy. If the firm produces more, it receives more free allowances – stimulating domestic production and reducing incentives to relocate to another country (stimulating domestic supply). This happens through two channels: mitigating carbon leakage in industry markets, and still giving incentives to reduce emissions intensities. There are, however, negative effects of OBA. OBAs' generous allocation of allowances could stimulate too much use of emission-intensive goods. Tax on consumption can counteract this, by taxing the use of this good.

3.5 Environmental Taxes and Cost effectiveness

A common criterion for assessing the effectiveness of an environmental policy is cost effectiveness. All agents have equal marginal abatement costs of emissions evaluated at the agent's chosen emission level. Cost effectiveness is a necessary condition for optimality (efficiency). The optimal tax rate appears when marginal abatement costs for each agent equal marginal damages evaluated at the aggregate optimal emission level, M^*.

$$MAC_i(m_i^*) = MAC_j(m_j^*) = MD(M^*)\forall i,j \in I$$

Marginal abatement cost (MAC) curve is the most common tool for representing cost-effectiveness. It can be applied to both supply-side and demand-side measures.

Unlike command and control instruments an environmental tax is a market system and is therefore cost effective. Polluters with lowest abatement costs (MAC_B), will abate and reduce their polluting output the most to pay a lower tax bill since it costs them less to abate than to pay a tax for not abating. Polluters with highest abatement costs (MAC_A) will abate and reduce their polluting output less and pay a higher tax bill as it costs more to abate than to pay a tax for not abating.

This is shown in the diagram below, Figure 3:6.

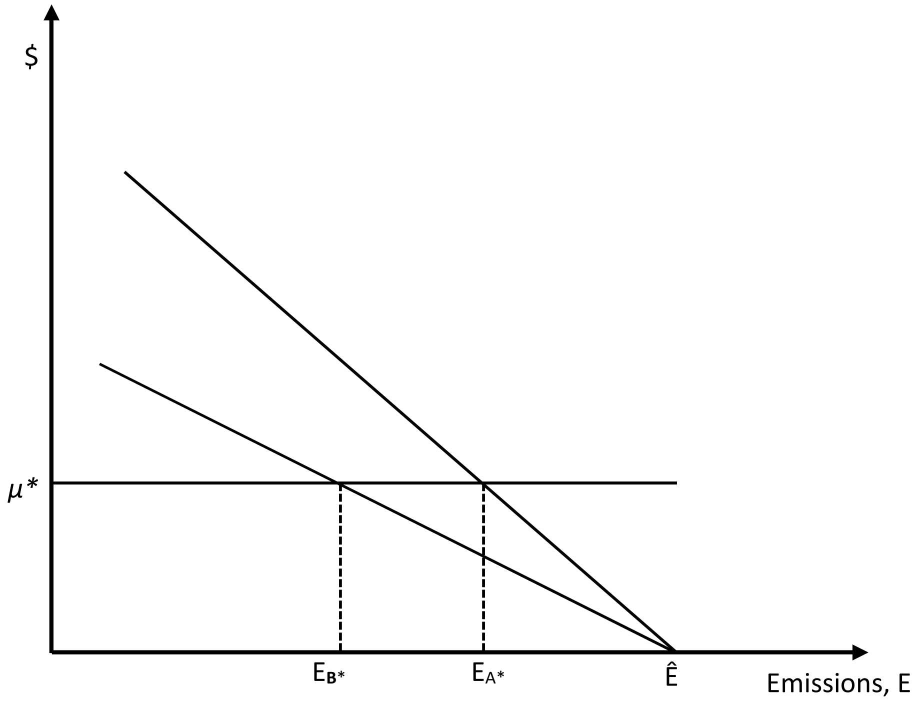

Figure 3:6, MAC curves for A and B. Source Perman et al. (2003)

Imposition of an emission tax μ^* will automatically satisfy the equimarginal principle because all polluters will set the tax equal to their MAC curve. MACs will be equalized across polluting agents for their chosen level of emissions. An emission tax is cost effective even if the regulator knows nothing about the marginal abatement cost of any of the sources.

4 Empirical approach and Data

4.1 Supply side measures

At any point in time, oil and gas production stem from a portfolio of field projects, involving fields at all stages of development. As in Figure 4:1; a significant part of oil and gas production involves investments that are already sunk.

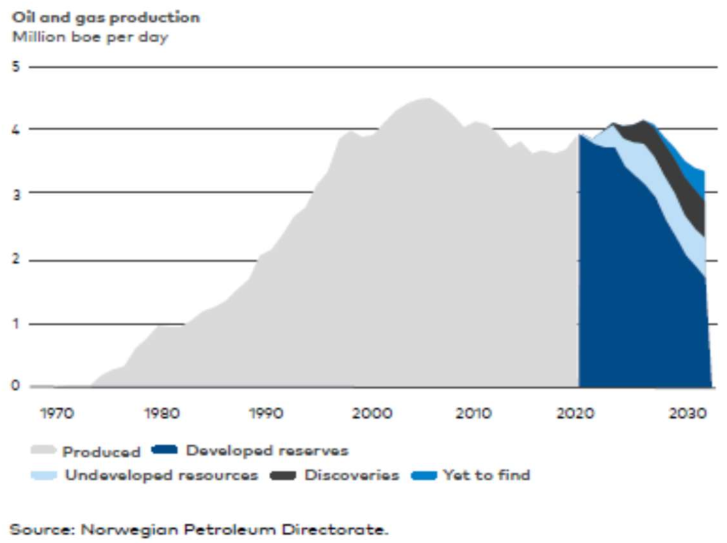

Figure 4:1, Oil and gas production

The question arises, which of these categories is supply side climate policies suitable? Limiting production for oil fields in the early phase of production and for oil fields currently under development is costly and controversial. The explanation is that the initial investment is yet to be recovered. Thus, the economically most feasible supply side measure relates to (new) oil discoveries. Since, the bulk of capital expenditures are not yet sunk and the revenues are more distant, measures targeted at these oil fields are less costly and less controversial. In comparison supply-side climate policies will be more costly and controversial for a large majority of current production volumes. Therefore, supply side measures appear more viable for production in the more distant future, i.e., exploration activities and field projects with marginal profitability.

I follow the perspectives of Fæhn et al. (2014), namely that the cost of supply side measures are the forgone profits for not extracting the oil resource. The starting point is to single out, oil fields that are characterized as marginal. Termination of such fields involves small profit loss per unit of CO_2 extracted. The intuition is simple, oil fields in the decline phase generally have higher costs than fields in the plateau phase. Marginal operating costs increases as oil declines.

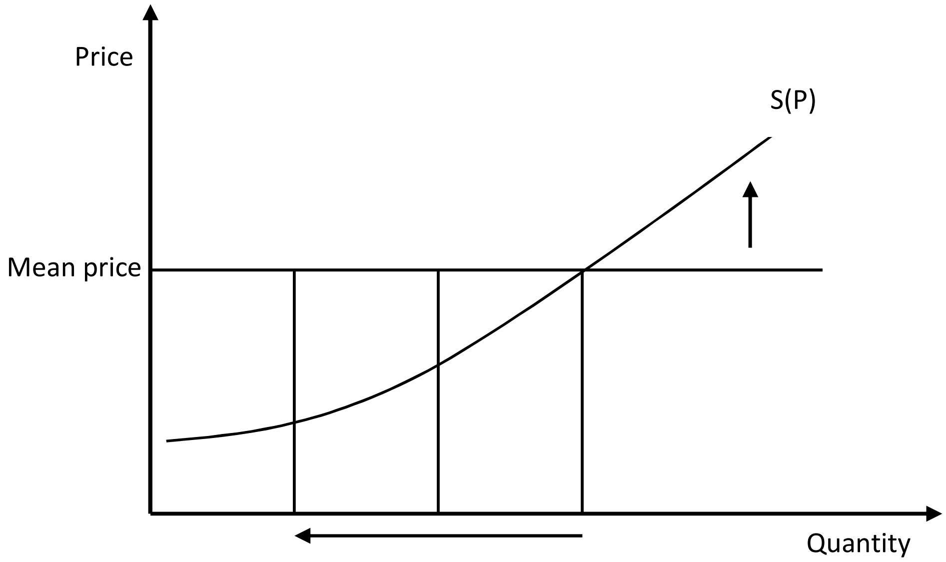

Figure 4:2, price dynamics in a constrained oil supply system

I will rely on secondary data to identify oilfields that can be categorized as those with marginal extraction costs close to the equilibrium price of oil. Ideally, these are the costliest oil fields to operate. Assuming a perfect market, in Figure 4:2, the market prices of oil will increase along the price curve of extracting the marginal (most expensive) unit, i.e. that which is most complex and difficult to get to.

4.2 The global effect of national unilateral climate policies

I will use a static model for my analysis and assume that there is free international trade in all fossil fuels. This assumption is to a certain degree in conflict with actual markets structure. The markets for fossil fuels are treated as one aggregate competitive market called the carbon market. Producers and consumers at home and abroad are assumed to be price takers. Price is treated as exogenous. The home country (or cooperating countries) acts to maximize total welfare. Therefore, the authorities of the home country are assumed to take into consideration the effect of their policies on international price of carbon. This implies that cooperative behaviour among OPEC countries is overlooked.

In a static model, which means I ignore the fact that fossil fuels are exhaustible resources, there are important dynamics properties of the market that I do not capture in my analysis like the green paradox. An intertemporal model would have been more appropriate to study the market equilibrium conditions in each time period. However, studies such as (Hoel, 2012), Venables (2011) and Österle (2012) show the relevance of analysing fossil fuels in a static framework as mine. Carbon leakage is limited to leakage through fossil fuel market channels. I ignore leakage through the energy intensive goods channels as this can be mitigated by compensation schemes for exposed industries or border tax adjustments Böhringer et al. (2012). The analysis in this thesis shares the standard limitations of all partial equilibrium analyses.

4.3 Theoretical model

There are two sets of countries. One set *K,* participates in climate cooperation while the other set *L,* does not. I will treat *K,* as one country to make the analysis more focused on the issue of aggregate impacts of supply side policies. Non cooperating countries interact with each other and with *L* only through markets. All countries benefit from consuming fossil fuels, but fossil fuels are costly to extract. Assume there is no climate policy in the non-cooperating countries. Assume that *K* implements climate policies with the aim of reducing carbon emissions to a target level say e^*. *K* can achieve this target by applying demand side policies, supply side policies or a combination of both policies. Taking e^* as exogenously given, I present this in Figure 4:3 below.

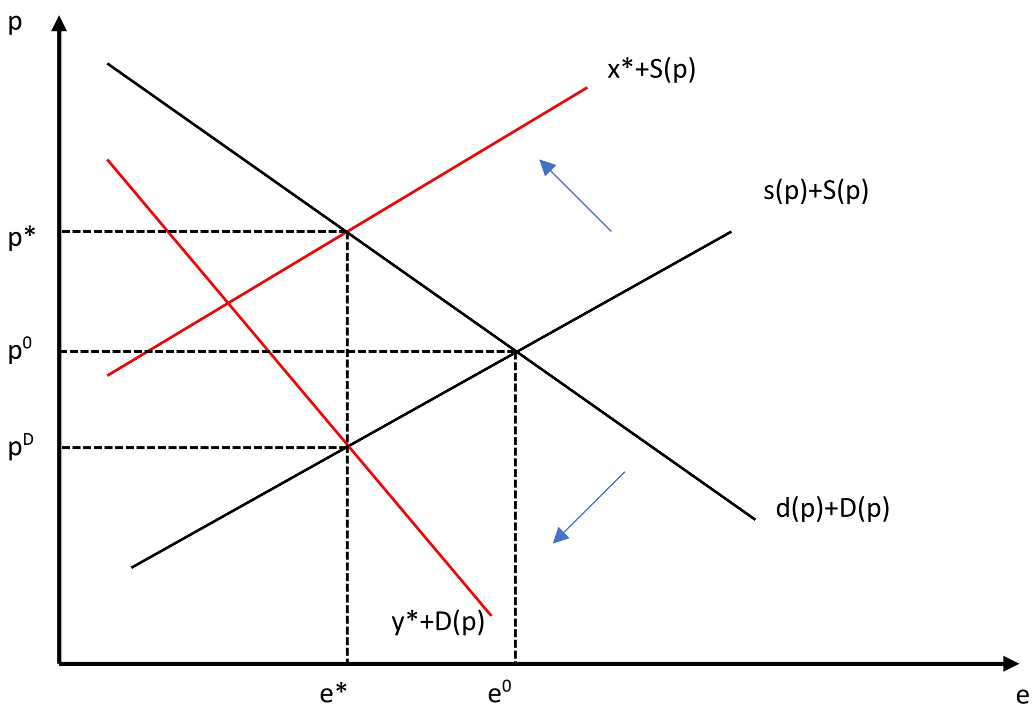

Figure 4:3 Demand side versus supply side policies

Explanation to nomenclature in Figure 4:4 : *s(p)* denotes country *K* supply, and *S(p)* foreign supply, similarly *d(p)* denotes domestic demand for country *K* and *D(p)* foreign countries domestic demand and *p* denotes international price of carbon.

If there is no climate policy in K, the equilibrium price and output level is at p^0e^0, at this point domestic supply $s(p)$ + foreign supply $S(p)$ equals domestic $d(p)$ demand +Foreign demand $D(p)$. To achieve emissions target e^*, the country can implement demand side policies or supply side policies. Let us first consider demand side policies. The implementation of demand side policies is expected to shift the demand curve downwards as indicated by the red arrow in Figure 4.3. The new demand curve shifts from $d(p)+D(p)$ to $y^*+D(p)$. To achieve the set target of emissions e^*, then y^* must be given by.

$$y^* + D(p) = s(p) + S(p) = e^*$$

From the above equation we can determine y^* and the equilibrium price under demand side policies. An alternative for K is to pursue supply side climate policies. Supply side climate policies (or limiting supply) will induce a leftward shift of the supply curve. The new supply curve will be $x^*+S(p)$ where supply is limited to x^*. To achieve the set target emissions e^*, then x^* must be given by.

$$d(p) + D(p) = x^* + S(p) = e^*$$

Similarly, we can determine x^* and the equilibrium price under supply side policies. Under supply side climate policies that limit fossil fuel production, the international price of carbon is higher compared to the price of carbon under demand side policies. This leads to reduce use of fossil carbon and larger scope for new energy saving techniques. Both are arguments in favour of supply side policies belonging in the optimal mix.

4.4 Empirical specifications

If a country $i \in K \cup L$ consumes y_i units of fuel, then i's benefit function is given by $B_i(y_i)$ which is twice differentiable. I also assume the benefit function is increasing and that B'_i is greater than zero. Country i's cost of extracting fossil fuel i, is denoted by $C_i(x_i)$. The cost function is assumed to be increasing and strictly convex. Only K counties consider environmental costs into their objective function, denoted as $H(E)$, where E denotes global emissions.

I also take it for granted that there is a world market for fossil fuels and p measures the equilibrium price. I specify the objective functions for non-cooperative countries and operative countries as follows.

$$U^i = B_i(y_i) - C_i(x_i) - p(y_i - x_i) \text{ if } i = L$$

$$U^i = B_i(y_i) - C_i(x_i) - p(y_i - x_i) - H(E) \text{ if } i = K$$

I assume that the government or the regulator of country *K,* which is willing to undertake unilateral action, will choose a climate policy that maximizes its citizens welfare i.e., consumer surplus and producer surplus given a certain target for global emissions reductions. Again, country *K* can pursue demand side or supply side climate policies to achieve its target in emissions reductions. The regulators maximization problem is specified as. Maximize welfare (*W*), subject to the global climate policy target *A*.

$$Max\ W = B_i(y_i) - C_i(x_i) - p(y_i - x_i) - H(E)$$

Subject to

$$E \leq E^0 - A$$

As emissions reductions are costly, the global climate policy target, *A*, will not be exceeded. This enables me to rewrite the above restriction to an equality constraint to avoid Kuhn-Tucker complications in the discussion. From first order conditions of the equality constrained Lagrangian I get:

$$\frac{B'_{y_i} - p}{E'_{y_i}} = \frac{p - C'_i(x_i)}{E'_{x_i}} = \lambda$$

Where λ is the shadow cost of the emission constraint, while E'_{y_i} and E'_{x_i} represents the marginal effects of increased demand and supply of fossil fuel *i* in country *K.*

From the first order conditions it can be shown as in Golombek et al. (1995), Fæhn et al. (2014) and Hoel (1994) that for the optimal climate policy the marginal costs of global emissions reductions through domestic supply side climate policies equals marginal costs of global emissions reductions through domestic demand side climate policies.

In this study I will only estimate the costs of the supply side measures which correspond to $p - C'_i(x_i)$. Since there is a large existing literature on estimates for demand side policies, I choose to rely on earlier research estimates for demand side estimates for comparison purposes.

4.5 Empirical specification

4.5.1 The functional form

In my numerical analysis, I will run regressions to estimate the marginal CO_2 abatement cost curve or *MAC*. The most important data for this study is the *MAC* of CO_2. How to evaluate the costs of measures that would reduce emissions by restricting oil supply is not so obvious. One documented approach is to consider the costs of such measures as the forgone rents for the companies that would have extracted the oil.

I will rely on historical oil fields data for the period 2009 to 2012. I need data on variable costs, investments costs and annual production volumes, which I will use to estimate the marginal production cost curve. I will apply a breakeven price of US $ 85 per barrel of Brent Blend. The breakeven price is essentially the cost to the producers of drilling and operating oil wells. I can now calculate the marginal forgone rents by subtracting the breakeven price from the marginal production costs. This yields the marginal forgone profits which in our case is the proxy for marginal abatement costs for not extracting the oil. I can now compare this with marginal abatement costs curve in the demand side from previous literature and conclude if supply side policies belong in the optimal mix.

4.5.2 Estimating marginal forgone rents and marginal production costs

I start by estimating the marginal production cost function using available data from the Norwegian Petroleum Directorate. Then I will proceed to estimate the marginal forgone rents. The results will be presented and discussed in the next chapter.

The marginal forgone rents and marginal production costs functions are estimated in log-linear regressions models.

$$Y = \beta_0 + \beta_1 X_1 + \cdots \beta_k X_k + \mathcal{E}$$

Where *Y* is the dependent variable i.e. the marginal production cost or the marginal forgone rents. X_1 *through* X_k are the explanatory variables whereas $\mathcal{E}$ is the error term.

Knowledge about the relationship between dependent and explanatory variables will allow us to simulate the effect of the proposed mitigation strategies by holding the regression coefficients *(β)* and the error terms (ε) constant and changing the explanatory variables according to the different measures.

5 Empirical results and discussion

In this chapter I first present descriptive information about the model variables. Secondly, the results from the statistical tests for both the main model and the alternative estimation model are presented. Thirdly, I discuss the model results and conclude with policy implications.

5.1 Descriptive Statistics

For the years 2009 to 2013 I have singled out oilfields that can be characterized as marginal, or in a declining phase of production. Investment costs in these fields was increasing, which could be an indication of intensive oil recovery activities. The dataset is a balanced panel, the sixteen oilfields produce throughout the time period of study. The fields are Glitne, Balder, Blane,Tor, Brage,Tordis, Gyda, Jotun, Statfjord, Norne, Sygna, Ula, Varg, Veslefrikk, Gullfaks, and Draugen. There are 48 observations of production and costs.

Table X.1 below contains an overview of the variables, together with mean values, standard deviations and minimum/maximum values for the selected fields.

Table 5.1. Summary statistics for the dataset with 80 observations.

Variable	Description	Unit	Mean	St. dev.	Min	Max
q	Oil production	Mill.Sm^3	1.024549	1.025678	.006161	4.689915
d	Reservoir depth	Meters	2596.88	627.30	1600	4000
w	Water depth	Meters	165.47	139.467	24.45	578.42
investment	Investment costs	Mill Noks	903.64	1066.74	2	5455
opc	Operational costs	Mill Noks	750.14	542.94	6	2654
oilprice	Brent crude oil price	Noks	94.55	20.45	61.74	111.57
tize	Original reserve size	Mill Sm3	95.60	101.63	0.9	384
wells_no	No. of wellbores	No.	63.19	71.86	1	278
tc	Total costs	Mill Noks	1653.46	1472.56	4	6603

Table A1 in the Appendix contains the empirical correlations between the variables.
To correct skewed distribution of residuals, natural logarithms were taken of all the variables. This also eases the interpretation of the results, as the slope coefficients can be read as elasticities.

5.2 Estimating the marginal production cost function

To estimate the marginal production cost function, a linear functional form is assumed.

$$lntc_{it} = \beta_0 + \beta_1 lnq_{it} + \beta_2 lnd_{it} + \beta_3 lnw_{it} + \beta_4 lnwells\_no_{it} + \beta_5 lni_{it} + \beta_6 lnopc_{it} + \beta_7 lnoilprice_{it} + \beta_8 lnsize_{it} + n_{\mathrm{i}} + u_{\mathrm{it}}$$

where tc_{it} the dependent variable (total costs) for oilfield *i* in year *t*. β_0 is the intercept, β_1 to β_8 are slope coefficients, n_{i} is the unobserved oilfields effects and u_{it} is the idiosyncratic error term. A full explanation of the abbreviations in the above equation is found in Table X.2 where the results are presented.

The Breusch and Pagan test rejects that $var(u) = 0$, which implies that $var(u)>0$. I conclude individual heterogeneity is a problem. Therefore, the pooled ordinary least squares (POLS) is not an appropriate model for this sample. An alternative model would be the fixed effects (FE) or the random effects model (RE). I thus run estimates of the FE and the RE estimators with robust standard errors. To determine the suitable model, I ran the Hausman test.

According to the Hausman test the coefficients of the RE-model are not significantly different to those of the FE model at 5% level of significance. I fail to reject the null hypothesis and I therefore conclude that the RE model is the most preferable among the model formulations I have undertaken. These results also suggest that the RE model is the consistent estimator for this study. Another advantage of the RE model is that it allows for an assessment of the time invariant variables.

The estimated variance to the random effects (*sigma_u* due to individual heterogeneity n_{i}) is higher for FE estimator. On the other hand, the estimated variance to the genuine error term or noise (*sigma_e* due to u_{it}) is equal for both the FE and RE models. If the noise (*sigma_u)* is greater than the random effects (*sigma_e*), there could be a problem with the model. However, the overall R^2 is higher in the RE model compared to that of the FE model. This agrees with the Hausman test which showed the RE estimator as the most consistent estimator for this study among the specifications tested.

Table 1.2 shows regression results using fixed effects and random effects models for comparison. The RE model allows estimates of both time-variant and time invariant variables.

Table 5.2 Estimation results for dependent variable total costs with RE and FE for comparison

Variable name	(1) Random effects	(2) Fixed effects
lnq (log of oil production)	-0.108 (-1.64)	-0.0253 (-0.59)
lnd (log of reservoir depth)	-0.659*** (-5.11)	0 (.)
lnw (log of water depth)	-0.0320 (-0.99)	0 (.)
lnoilprice (log of oilprice)	-0.152 (-1.43)	-0.0633 (-0.57)
lni (log of investments)	0.231*** (4.95)	0.248** (3.07)
lnopc (log of operational costs)	0.799*** (18.51)	0.726*** (6.18)
lnlagoilprice (log of lagged oil price)	-0.0240 (-0.40)	-0.0269 (-0.48)
lnwells_no (log of wellbores number)	0.116** (2.93)	0 (.)
Constant	6.226*** (5.46)	1.338 (1.37)
Observations	80	80
R^2	0.9848	0.9749
Sigma_u	.0320	.235
Sigma_e	.207	.207
rho	.023	.56

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The first variable in the table is *lnq* i.e. oil production in million standard cubic meters. Its parameter estimate is not significant at 5% or 10% level of significance and with a negative sign. When I squared the variable and regressed with the other variables the resultant coefficients were also insignificant. Consequently, I did not pursue that issue further.

Reservoir depth (*lnd)* enters very significantly at a 1% level of significance (p-value below 0.01) with a negative sign. 1% increase in reservoir depth would result in a decrease in total costs of 0.66% ceteris paribus. My intuition is that, reservoir depth is a time invariant variable, its costs are initial and once incurred are not repetitive and thus not so relevant in this study. Still, I choose to keep it in the regression as it reduces the unexplained variation in the data.
I expected costs of extracting oil in the marginal fields under study to be increasing significantly as reservoir depth declined. The deeper the reservoir, the more energy intensive it is to extract the oil. The same intuition applies for water depth in the area. However, water depth turned out to be insignificant in my model, and I will not discuss it further.

The variables *lni, lnopc* and *lnwells_no* were significant at 1% level of significance with a positive sign. Holding other variables constant, a 1% increase in investment resulted in 0.23% increase in total costs and 1% increase in number of wells resulted in 0.12% increase in total costs. Similar interpretation follows for operational expenses. This is expected, marginal resources are costly to extract, operating costs including energy input increases as remaining reserves declines. Since the cheap to extract oil has already been extracted the oil companies resort to improved oil recovery (IOR) activities which involves new investments. These new technologies and investments are expensive. Thus, one can conclude this is indicative of IOR. Notably, these oil fields also have higher emission intensities. Similarly, the investments linked to several wells is more elaborate relative to investments in a single well.

5.3 Marginal abatement costs

In this study, we are interested in marginal abatement costs. Having run estimates of the coefficients of the cost function I can use these estimates to calculate the marginal costs. This is important for calculation of the marginal forgone profits for not extracting the oil. To calculate the marginal forgone rents by constrained oil production, I apply the average oil price over the period (USD 85 per barrel of Brent Blend) as noted earlier in data and methodology. The marginal abatement cost curve is given by the marginal producer surplus i.e. the price minus marginal costs estimated above. I show this graphically below.

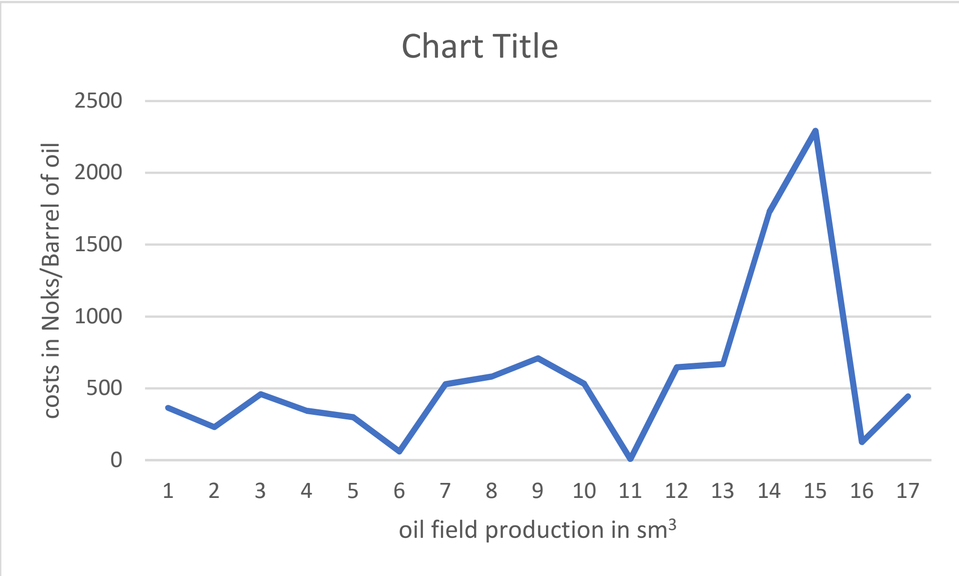

Figure 5:1,MC curve for constrained production

I can now calculate the marginal forgone rents by subtracting the breakeven price from the marginal production costs. This yields the marginal forgone profits which in our case is the proxy for marginal abatement costs for not extracting the oil. I can now compare this with marginal abatement costs curve in the demand side from previous literature and conclude if supply side policies belong in the optimal mix.

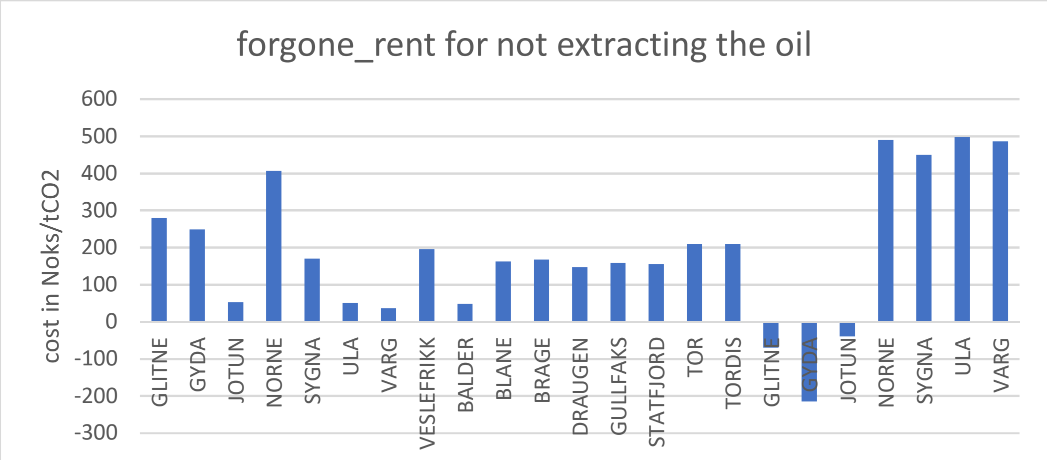

Figure 5:2 Forgone rents for not extracting oil

The maximum value for forgone rent amounts to 500Noks/tCO_2 while the minimum corresponds to -200Noks/ tCO_2. In previous literature, Fæhn et al. (2014) showed the cost of demand side policy to be the marginal costs of forgone oil consumption. To achieve a target of 8.4 million tonnes of CO_2 abatement the Fæhn et al. (ibid.) estimated marginal costs of forgone oil consumption of 576USD per ton of CO_2. A million standard cubic meters leads to 2.65tonnes of CO_2 emissions when the oil is combusted.

Plotting the two curves together helps give a better picture of how the optimal mix would look like. I apply the historical exchange rate for the period under study i.e.1USD=5.6Noks.

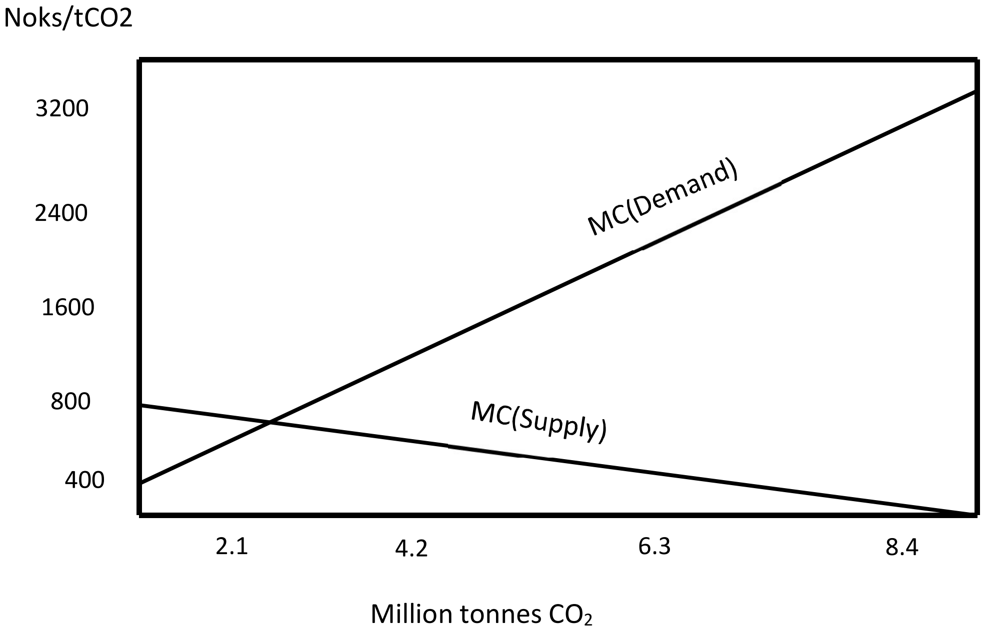

Figure 5:3 Marginal cost curves for supply and demand side policies for CO_2 emissions reductions

Here the key observation is that the MC for supply side measures lies below the MC demand side measures implying supply side measures belong in the optimal mix.

5.4 Global emissions and constrained supply

The lion's share of CO_2-emissions from oil occurs when the oil undergoes combustion.

According to OGP (2012), GHG emissions per unit production worldwide averaged 1165kg CO_2 equivalents per 1,000 toe hydrocarbons produced. Middle East emission intensity averaged 374 kg CO_2 equivalent. The European figure is 616 kg CO_2 equivalents. According to Statistics Norway the figure for Norwegian emission intensity averages at 440kg CO_2 equivalents. In my economic review I stated that each barrel of oil extracted in the Norwegian continental shelf contains carbon, that once refined into products and burned, releases at least 400 kg of CO_2 equivalents. I also noted that elasticities of demand and supply are key in the analysis of how limiting oil supply would drop global emissions. Leakage is a key concern when one considers unilateral actions. Leakage rate is dependent on the elasticity of supply and elasticity of demand.

Widely used economic tools (price elasticities) enable economic modelling of different price-response dynamics. Using a simple economic model, I estimate that for each barrel of Norwegian oil not extracted, 0.35 to 0.78 barrels of oil would be produced elsewhere. For robustness against the uncertainties around the equilibrium price I conduct a sensitivity analysis by varying the elasticities of demand and elasticities of supply found in previous literature Cooper (2003),Brook et al. (2004) Fæhn et al. (2014). The results are displayed in table 1.3. below.

Table 5.3 Increase in annual crude oil consumption per barrel of added Norwegian oil production under a range of demand and supply elasticities.

	elasticity of supply (*Es*)		
elasticity of demand (*Ed*)	0.1	0.13	0.6
-0.054	0.35	0.29	0.08
-0.2	0.67	0.61	0.25
-0.36	0.78	0.73	0.38

This follows the standard approach of demand and supply analysis outlined in Perloff (2015). Assuming small changes in supply, a change in consumption can be estimated as the shift in the supply curve (change in production) multiplied by the elasticity of demand divided by the difference between the elasticities of demand and supply, $Ed/(Ed - Es)$. Therefore, changes in emissions can be expressed as follows.

$$\Delta Emissions = EF_{pr} - EF_{rf} + (EF_{rf} * \frac{\Delta consumption}{\Delta production})$$

where $\Delta Emissions$ is change in emissions measured in tonnes CO_2 equivalent.
EF_{pr}-is the emissions factor, per unit of fuel handled, life cycle basis; and EF_{rf} is the emissions factor, per unit of fuel displaced reference fuel, lifecycle basis. $\Delta consumption$ is the increase in fuel consumption resulting from increased production and finally $\Delta production$ is the increase in production of the fuel.

To apply this to the case of Norwegian oil, I take the estimated emissions factor of 440kg CO_2 equivalent from Statistics Norway. I consider the most likely substitute of the Norwegian crude to be the middle east sour whose emissions factor is 374kg CO_2. Applying this to the equation above yields a GHG emissions impact of 317kg CO_2 equivalent. This choice is consistent with a supply elasticity of 0.1 and a demand elasticity of -0.2.

Another way of approaching this is to take 1 minus the 0.35 to 0.78 computed above. This yields a net reduction of 0.65 and 0.22 barrels of oil in global oil consumption for each barrel of oil left on the ground. Multiply this with the Norwegian emissions factor of 440kg CO_2 equivalent and we get almost the same figures.

We saw that in a static framework the marginal abatement costs are the forgone rents for not extracting the oil. A measure of cost effectiveness can then be computed by dividing lost profits (as a proxy for costs) by the drop in global CO_2 emissions for each barrel of oil not extracted. From my estimates for forgone rents, the cost effectiveness of constraining oil production from the Ula, Varg, and Norne oilfields would then be 1,250Noks per t CO_2 (i.e. 500Noks per barrel divided by 0.4 t CO_2 per barrel). Even though this shows the costs to be higher than what I estimated earlier with Random effects model, they are still lower than the costs for the demand side measures which go beyond the 3,000Noks. This confirms my argument that supply-side measures belong in the optimal mix and Norway would do better to consider supply side measures in addition or combination with demand side measures.

5.5 Policy implications

I suppose the regulator's goal is to limit extraction by a certain percentage in relation to a future reference level. The reference level is the result of the licence allocation principles and petroleum tax rules in use. The following policy instruments namely; production tax, restrictions on licence awards and combinations of these, are possible prospects the regulator or government can apply to help achieve climate goals through supply side cuts.

However, Norwegian authorities have been cautious about adjusting or changing the taxation system, at least for already developed fields. Additional taxes may be interpreted as changing the rules. Considering the many decisions an oil company undertakes before the final product is availed in the market an interference in the tax system increases the risk of doing business on the Norwegian continental shelf. This destabilizes an entire industry and given the importance of the industry the government has good reasons not to interfere.

Therefore, it is much easier to make an argument for levying a large production tax on extraction from undeveloped fields, unexplored areas and even developed fields necessitating upgrading through IOR projects than on approved extraction from developed fields.

6 Conclusions

6.1 Main findings

This thesis investigates unilateral climate policies; demand side versus supply side policies. Since there is vast literature on the demand side measures, I have chosen to investigate supply side measures, and rely on existing research on demand side to argue if supply side measures belong in an optimal mix. The research sought to answer the following question:

Given Norway's 2020 domestic target for emission reduction, is it cost effective for Norway to pursue a standalone demand-side or supply side policy or is a combination of demand and supply side policy better?

Findings from the research are in favour of an optimal combination rather than standalone demand or supply side measures. It was observed that supply side policy indeed belongs in the optimal mix. A look at the forgone rents or lost profits for not extracting the oil, which in this study are the costs of measures Norway would take to reduce emissions by limiting supply where lower under supply side measures compared to demand side measures. An alternative model also looking at elasticities of supply and elasticities of demand estimated the supply side climate measures for reducing global emissions and found it to be less costly compared to demand side measures, for instance the forgone rents for not extracting the oil in oilfields Ula, Varg and Norne amount to almost 1,250Noks per ton of CO_2 equivalent for each field. My study did not look at the optimal policy but rather sought to investigate whether supply side policy belonged in the optimal mix. Moreover, my study confirms the hypothesis that supply-side measures will at least do better than some demand side measures. The Random effects model with total costs as dependent variable showed investments for drilling purposes and operational expenses significant at 1% level of significance.

In sum, limiting oil extraction constitutes an important part in the optimal mix of demand side- and supply-side climate policies in Norway. It is the increasing the marginal costs of emissions reductions on either the supply side or the demand side that indicates a combination of the two is optimal.

6.2 Limitations of the study

The main challenge I faced in this study was access to required data. The cost data was difficult to find. Hence, within the limited time available for my study I was unable to get hold of the desired cost data. One implication of this is that I could not look greater effects on the cost function like cost shares of labour, cost shares of different inputs but rather looked on the generalized cost effects.

6.3 Suggestions for further research

One could look at the adaptations of the taxation system and the adjustments needed to restrain exploration activities. If supply side approaches were to gain additional ground, these stand out as interesting options for further investigation.

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Appendix

Appendix 7-A correlation matrix between variables

```
. corr lntc lnq lnd lnw  lnoilprice lni lnopc lnlagoilprice lnwells_no
(obs=80)

             |     lntc      lnq      lnd      lnw lnoilp~e      lni    lnopc lnlago~e lnwell~o
-------------+---------------------------------------------------------------------------------
        lntc |   1.0000
         lnq |   0.7639   1.0000
         lnd |  -0.3159  -0.3992   1.0000
         lnw |   0.2809   0.3197  -0.3018   1.0000
  lnoilprice |   0.0216  -0.2033  -0.0000  -0.0000   1.0000
         lni |   0.8412   0.8034  -0.1267   0.2194   0.0555   1.0000
       lnopc |   0.9666   0.6936  -0.3054   0.2780   0.0113   0.7165   1.0000
lnlagoilpr~e |  -0.0556  -0.1239  -0.0554  -0.0170   0.2617  -0.0363  -0.0653   1.0000
  lnwells_no |   0.8839   0.7094  -0.0968   0.3362   0.0000   0.7763   0.8599  -0.0589   1.0000
```

Appendix 7-B Regression results for RE model

```
. xtreg lntc lnq lnd lnw  lnoilprice lni lnopc lnlagoilprice lnwells_no, re ro

Random-effects GLS regression                   Number of obs      =        80
Group variable: name                            Number of groups   =        16

R-sq:  within  = 0.7279                         Obs per group: min =         5
       between = 0.9976                                        avg =       5.0
       overall = 0.9848                                        max =         5

                                                Wald chi2(8)       = 130613.02
corr(u_i, X)   = 0 (assumed)                    Prob > chi2        =    0.0000

                                  (Std. Err. adjusted for 16 clusters in name)
------------------------------------------------------------------------------
             |               Robust
        lntc |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         lnq |  -.1079773   .0656466    -1.64   0.100    -.2366423    .0206876
         lnd |  -.6589672   .1288321    -5.11   0.000    -.9114735   -.4064608
         lnw |  -.0320432   .0323336    -0.99   0.322     -.095416    .0313296
  lnoilprice |  -.1521423    .106628    -1.43   0.154    -.3611293    .0568446
         lni |   .2309234   .0466556     4.95   0.000     .1394802    .3223666
       lnopc |   .7989713   .0431538    18.51   0.000     .7143913    .8835512
lnlagoilprice |  -.0240482   .0594091    -0.40   0.686    -.1404879    .0923915
  lnwells_no |   .1157436   .0395655     2.93   0.003     .0381966    .1932906
       _cons |   6.226326   1.141384     5.46   0.000     3.989255    8.463398
-------------+----------------------------------------------------------------
     sigma_u |  .03204802
     sigma_e |  .20771436
         rho |  .02325156   (fraction of variance due to u_i)
------------------------------------------------------------------------------

.
end of do-file
```

Appendix 7-C Regression results for the FE model

```
. xtreg lntc lnq lnd lnw  lnoilprice lni lnopc lnlagoilprice lnwells_no, fe ro
note: lnd omitted because of collinearity
note: lnw omitted because of collinearity
note: lnwells_no omitted because of collinearity

Fixed-effects (within) regression               Number of obs      =        80
Group variable: name                            Number of groups   =        16

R-sq:  within  = 0.7420                         Obs per group: min =         5
       between = 0.9867                                        avg =       5.0
       overall = 0.9749                                        max =         5

                                                F(5,15)            =     38.71
corr(u_i, Xb)  = 0.5910                         Prob > F           =    0.0000

                                   (Std. Err. adjusted for 16 clusters in name)
------------------------------------------------------------------------------
             |               Robust
        lntc |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         lnq |  -.0252835   .0426267    -0.59   0.562    -.1161402    .0655732
         lnd |          0  (omitted)
         lnw |          0  (omitted)
  lnoilprice |  -.0633341    .110735    -0.57   0.576    -.2993602    .1726921
         lni |   .2482381    .080905     3.07   0.008     .0757932    .4206831
       lnopc |   .7260269   .1174982     6.18   0.000     .4755855    .9764684
lnlagoilprice|  -.0269141   .0564099    -0.48   0.640    -.1471489    .0933207
  lnwells_no |          0  (omitted)
       _cons |   1.337711   .9783436     1.37   0.192    -.7475792    3.423001
-------------+----------------------------------------------------------------
     sigma_u |  .23553805
     sigma_e |  .20771436
         rho |   .5625253   (fraction of variance due to u_i)
------------------------------------------------------------------------------

.
end of do-file
```

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