

Prices versus Quantities: The Impact of Fracking on the Choice of Climate Policy Instruments in the Presence of OPEC

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Abstract

This paper analyzes the impact of declining extraction costs of shale oil producers on the choice of the policy instrument of a climate coalition in the presence of a monopolistic oil supplier such as OPEC. Shale oil producers' extraction costs represent an upper bound for the oil price OPEC can charge. Declining extraction costs ultimately limit OPEC's price setting behavior and thus impacts the optimal climate policy of the climate coalition.

A pure cap-and-trade system is weakly welfare-inferior relative to a carbon tax for the climate coalition. While high extraction costs allow OPEC to appropriate the whole climate rent in case of quantity regulation, declining extraction costs imply OPEC to capture only a part of the climate rent. A carbon tax always generates positive revenue and thus is welfare-superior in general. However, low extraction costs prevent OPEC from exerting its market power, leading the climate coalition to implement the Pigouvian tax in the first place. Both market-based instruments are equivalent in this case. Complementing a quota with a base tax cannot outperform a pure carbon tax.

Keywords: fossil fuel taxation, prices versus quantities, international redistribution, global warming.

JEL Classification Numbers: H23, Q31, Q54, Q58.

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1 Introduction

In the Paris Agreement from 2015, the conference of the parties called for 'holding the increase in the global average temperature to well below 2°C above pre-industrial levels' (UNFCCC 2015: Art. 2a) as suggested by the latest reports of the Intergovernmental Panel on Climate Change (IPCC 2014) and agreed to limit the exhaust of greenhouse gas emissions. Aiming at overcoming the free rider problem that is at the heart of global warming, each country put forward country-specific emissions reduction targets as a first step of coordinated action. Limiting global carbon dioxide (CO₂) emissions necessarily impacts the demand for fossil fuels because the vast majority of CO₂ emissions stem from the combustion of fossil fuels. Thus, coordinated climate action by the major fossil fuel consuming countries can also be thought of as forming a climate coalition that acts as a demand cartel in the fossil fuel market. At the same time, any regulation of CO₂ emissions inevitably affects the supply of the owners of fossil fuels such as oil.

The oil market is characterized by the market power of the extractors, where the Organization of the Petroleum Exporting Countries (OPEC) accounts for almost half of the world's oil production and nearly 75% of proven oil reserves, leaving OPEC as the dominant player in the oil market. Given the market power of OPEC and the demand cartel in form of the climate coalition, the market structure in the oil market can be characterized as a bilateral monopoly. Under this market structure, previous papers find that the climate coalition is strictly better off under a carbon tax than under a cap-and-trade system. Intuitively, a fixed quota causes the effective demand for fossil fuels to be more inelastic, which allows OPEC to extract a higher share of the climate rent, thereby leaving less revenue for the climate coalition. However, OPEC is not the sole supplier of oil, but faces increasing competition due to the evolution of the shale oil industry. Even though the extraction costs of shale oil are still much higher than those of OPEC's conventional oil, technological progress in the shale oil industry has dramatically decreased the extraction costs within the last years. This

paper explores the consequences of declining extraction costs of OPEC's competitors on the rent distribution between the climate coalition and OPEC as well as the implications for the choice of the climate policy instrument.

Many countries, among which there are major emitters of CO₂, such as the European Union, China and some U.S. states, have already launched or are planning to launch emissions trading schemes. Thus, it seems to be very likely that cap-and-trade turns out as the predominant climate policy instrument. However, the economics literature predominantly favors a carbon tax over cap-and-trade for various reasons.¹ One reason for this preference is the existence of market power in the oil market, first explored by Berger et al. (1992). Accounting for OPEC's dominant role with respect to its competitors within a competitive fringe model, Berger et al. (1992) analyze OPEC's reaction towards carbon taxes and quotas for a given level of CO₂ emissions. Strand (2009) endogenizes the level of CO₂ emissions for both instruments, but does not incorporate fossil fuel producers other than OPEC. This paper fills the research gap between both papers by deriving the optimal level of CO₂ emissions (in contrast to Berger et al. 1992) and accounting for the impact of the competitive fringe (in contrast to Strand 2009) on the choice of the policy instrument.

Following Berger et al. (1992) and Strand (2009), the research question is answered within a static setting, where the two players, i.e. the climate coalition and OPEC, strategically interact with each other due to their dominant roles in the oil market. The shale oil industry is assumed to have positive constant marginal extraction costs higher than those of OPEC. The extraction costs then represent an upper bound for the oil price that OPEC can charge. If these costs are declining, so does the upper bound, which ultimately limits the price setting behavior of OPEC and thus impacts the optimal climate policy of the climate coalition.

Given the market power of OPEC, its reaction towards climate policy differs between

¹See Goulder and Schein 2013 for a recent review.

a carbon tax and a fixed quota, which is why the climate coalition generally prefers one instrument over the other. In particular, as pointed out by Berger et al. (1992), OPEC's reaction towards a fixed quota is to marginally undercut that quota, which drives the permit price to zero and leaves no revenue for the climate coalition. This result also holds true in this paper as long as the fringe's marginal extraction costs are sufficiently high. For low extraction costs, OPEC still marginally undercuts the quota, but can capture only a part of the climate rent because the oil price is limited by the fringe's extraction costs.

Relative to a quota, a carbon tax generates positive revenue for the government and thus is welfare-superior for the climate coalition in general. However, low extraction costs of the fringe prevent OPEC from charging the monopolistic price and from exerting its market power. By anticipating this, the climate coalition optimally implements the Pigouvian tax in the first place and it turns out that the price and quantity instruments are equivalent in this case. However, for high extraction costs, the climate coalition strictly prefers the carbon tax, implying price regulation to weakly dominate quantity regulation. Complementing the quantity regulation by a base tax, as proposed by Schöb (2010), allows the climate coalition to retain some of the carbon revenue, but cannot outperform the pure price regulation.

1.1 Related literature

In a dynamic setting, early papers focused on using import tariffs to capture exporter's resource rents starting with Bergstrom (1982) and Karp and Newbery (1991).² More recently, several papers have discussed climate policy as a means to capture foreign resource rents (Wirl 1995, Wirl and Dockner 1995, Amundsen and Schöb 1999, Rubio and Escriche 2001, Liski and Tahvonen 2004 and Eisenack et al. 2012). Wirl (2012)

²Keutiben (2014) analyzes the impact of a competitive fringe of oil suppliers on the optimal import tariff and finds that the presence of competitors enhances the ability of the importer to capture the exporter's resource rent.

explicitly compares price and quantity strategies within a dynamic game between a climate coalition and OPEC and finds that both players are better off under the price strategy. Karp et al. (2015) extends this model by incorporating a non-strategic third country that also consumes oil, but does not belong to the climate coalition. Even this small extension prevents the derivation of any qualitative result and forces the authors to solve the problem numerically. Hence, some authors have started using static settings in order to analyze more complex scenarios such as the incorporation of a competitive fringe.

Berger et al. (1992) were the first to analyze the reaction of a dominant oil supplier towards price and quantity instruments while accounting for a competitive fringe. In the absence of the fringe, OPEC's best reaction towards a fixed quota is to marginally undercut that quota, thereby extracting the whole climate rent and leaving no carbon revenue for the climate coalition. In contrast, a carbon tax generates some revenue for the importing countries, which is why it is welfare-superior to a cap-and-trade system. Incorporating a competitive fringe that supplies oil at increasing marginal extraction costs causes the residual demand to turn downwards, forcing OPEC to reduce its price. However, the effective demand in the case of quantity regulation remains perfectly inelastic at the quota, which allows OPEC to charge a higher price relative to a carbon tax, implying a carbon tax to continue to be preferred by the importing countries. While Berger et al. (1992) compare price and quantity regulation for an exogenously given level of oil consumption, the present paper derives the welfare-optimal oil quantities for each policy instrument and contrasts the respective welfare levels.

Strand (2009) endogenizes the oil consumption by maximizing the climate coalition's welfare, but does not incorporate a competitive fringe into his analysis. As in Berger et al. (1992), quantity regulation allows OPEC to capture the whole climate rent. Anticipating this, the climate coalition may find it optimal to reduce the quota to zero. A marginal increase of the quota starting at zero increases the utility from oil consump-

tion, but this welfare gain is entirely captured by OPEC. Since the permit price is zero, the climate coalition suffers a welfare loss due to the additional damage from global warming. However, raising the quota beyond zero may eventually improve the climate coalition's welfare because it forces OPEC to reduce its oil price in order to capture the climate rent, which finally leads to an increase of the consumer surplus. If the consumer surplus outweighs the damage from global warming, then the climate coalition optimally implements a positive quota equal to the quantity that an unregulated monopolist would choose. Any quota beyond that quantity is ineffective because OPEC would optimally reduce its supply accordingly. Since a cap-and-trade system does not generate any revenue, whereas a carbon tax leaves some revenue for the climate coalition, Strand (2009) concludes that price regulation strictly dominates quantity regulation.

In order to retain some revenue from the cap-and-trade system, Schöb (2010) proposes to complement the quota by a base tax. He finds that this dual instrument enables the climate coalition to generate the same revenue as from implementing a carbon tax. In contrast to Schöb (2010), the present paper derives the optimal level of oil consumption while accounting for a competitive fringe.

The remainder of the paper is organized as follows. Section 2 presents the model that is used to analyze the research question. Section 3 compares a carbon tax with a cap-and-trade system and works out the impact of the competitive fringe on the choice of the climate policy instrument. In Section 4, the dual instrument that complements the quantity regulation with a base tax is analyzed. Finally, Section 5 discusses the results and concludes.

2 The model

Following Berger et al. (1992) and Strand (2009), I set up a static model, which is appropriate as long as the analysis covers the medium run, i.e. the next 20 to 30 years.³ There are two groups of countries: the climate coalition and a cartelized group of fossil fuel exporters such as OPEC. OPEC is assumed to be the dominant oil producer, whereas the climate coalition as a demand cartel is the sole oil consumer, but also hosts a number of small firms that extract oil at higher marginal costs than OPEC.⁴

The timing of the game is the following. First, the climate coalition chooses the policy instrument and sets the level of the carbon tax or the quota respectively. Second, OPEC moves by determining its exporter price or its quantity. This timing reflects the fact that international climate negotiations that involve many countries take much more time than the coordination of a small subgroup of fossil fuel exporting countries that have already been cooperating for several years. Third, the competitive fringe determines its extraction amount. The problem is solved by backwards induction.

3. Stage: Competitive fringe

The competitive fringe represents small competitive firms, operating in the shale-oil industry. All firms take the resource price net of taxes p as given and are assumed to have the same constant marginal extraction costs $c > 0$. They maximize their profits $\pi_F(R) = pR - cR$ by choosing the optimal amount of extraction R and the supply function reads

$$R_F(p) = \begin{cases} \infty & \text{if } p > c \\ [0, \infty] & \text{if } p = c \\ 0 & \text{if } p < c. \end{cases} \quad (1)$$

³Even though the extraction of fossil fuels is inherently a dynamic problem, which requires dynamic solution techniques, I take the warning of Wirl (2012) seriously, who states that 'any substantial extension may render closed form solutions impossible or intractable' (Wirl 2012, p. 227).

⁴As shown by Strand (2013), the qualitative results do not alter when introducing a second non-strategic oil consuming country which can be thought of as rest of world.

2. Stage: OPEC

As a dominant player in the oil market, OPEC decides upon its extraction before all other firms move, taking the policy of the climate coalition as given. For simplicity, the marginal extraction costs of OPEC are normalized to zero, reflecting the fact that OPEC's extraction costs are still far below those of its competitors.⁵ In contrast to the climate coalition, OPEC does not care about the damage from global warming caused by the combustion of fossil fuels. Let $q = p + t$ be the consumer price with t be the price of carbon (either tax or permit price) and $R(q)$ as well as $q(R)$ be the (inverse) demand for oil, then the profits of OPEC read

$$\pi(p, t) = pR(p + t) \quad \text{and} \quad \pi(R, t) = (q(R) - t)R. \quad (2)$$

As will be shown in the next section, OPEC's profit maximizing strategy depends on the choice of the policy instrument of the climate coalition.

1. Stage: Climate coalition

The climate coalition is the sole consumer of oil. The utility of the representative consumer of a representative country belonging to the climate coalition is characterized by decreasing marginal utility. Even though most of the results of this paper can be also derived using a general utility function, I follow Strand (2009) and assume the utility to be linear-quadratic in order to obtain closed-form solutions that allow for explicit welfare comparisons. The utility function reads

$$U(R) = aR - (1/2)\gamma R^2, \quad (3)$$

which leads to a linear demand function. Taking the consumer price for oil q as given, the representative consumer maximizes her utility and the demand function as well as

⁵In fact, marginal extraction costs of OPEC are not zero, but positive ranging from 3 USD/barrel (bbl) for Saudi Arabia to 20 USD/bbl for Venezuela and are far below the marginal extraction costs of shale-oil, which are estimated to be around 70 USD/bbl according to Knoema (2014).

the inverse demand function are given by

$$\max_R U(R) - qR \Leftrightarrow q(R) = a - \gamma R \text{ and } R(q) = (1/\gamma)(a - q). \quad (4)$$

The climate coalition experiences damage from global warming that arises from the combustion of fossil fuels. For simplicity, the combustion of one unit of oil is assumed to emit one unit of CO₂, causing a constant marginal environmental damage of ψ . This reflects the basic characteristics of climate change in the medium term. In the following, I assume $\psi < a$, meaning that the marginal environmental damage is lower than the marginal utility of the first unit of oil.

Assuming the tax revenues to be redistributed lump-sum to the consumers, the social welfare of the climate coalition is based on a national concept, consisting of the consumer surplus, the lump-sum transfers and the environmental damage. The welfare function is given by

$$W(R, p) = aR - (1/2)\gamma R^2 - pR - \psi R, \quad (5)$$

where the tax payments and the lump-sum transfers cancel out. The global welfare maximum, i.e. the maximum of the joint welfare of the climate coalition and OPEC, is given by $R_{fb} = (1/\gamma)(a - \psi)$. However, due to the opposing incentives of the climate coalition and OPEC, the first-best will not be achieved as long as the players do not cooperate when choosing their policies. In principle, the climate coalition may maximize its national welfare either by a price or a quantity instrument. However, the reaction of OPEC is different in both cases as will be seen in the next section.

3 Comparing climate policy instruments

This section compares a carbon tax with a cap-and-trade system. Let us first summarize the analysis without the competitive fringe as in the model of Strand (2009).

3.1 Prices versus quantities without a competitive fringe

The choice of the climate policy instrument in the first stage impacts OPEC's reaction in the second stage as shown in Figure 1.

Figure 1: OPEC's reaction towards price and quantity instruments

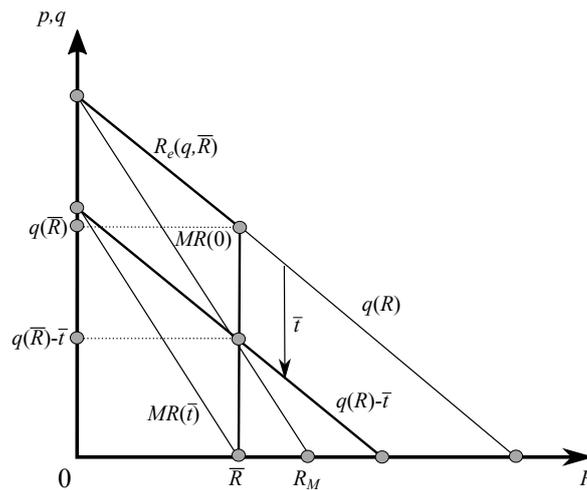


Figure 1 depicts the inverse demand function $q(R)$, the inverse demand function less the tax $q(R) - \bar{t}$, the marginal revenues $MR(0)$ and $MR(\bar{t})$, the quantity of the unregulated monopolist R_M , the quota $\bar{R} < R_M$ and the effective demand function $R_e(q, \bar{R})$. Imposing a quota causes the effective demand for OPEC to be kinked at $(\bar{R}, q(\bar{R}))$ so that OPEC's optimal reaction is to supply \bar{R} at a price $q(\bar{R})$.⁶ Charging a price of $q(\bar{R})$ drives the permit price to zero, implying the climate coalition to generate no revenue and OPEC to extract the whole climate rent.⁷

If the climate coalition was to impose \bar{R} by a carbon tax, it would need to implement a tax level of \bar{t} , so that OPEC's marginal revenue equals its marginal costs at \bar{R} . In this

⁶OPEC cannot sell more than \bar{R} , even if it was to reduce its price. Raising the price above $q(\bar{R})$ is also not optimal because the marginal revenue exceeds the marginal costs (zero) for all $\bar{R} < R_M$.

⁷When permits are auctioned to the consumers, the permit price emerges as the difference between the consumer price $q(R)$ and the price that OPEC charges.

case, OPEC optimally charges an oil price of $q(\bar{R}) - \bar{t}$, leaving a positive tax revenue equal to $\bar{t} \cdot \bar{R}$ for the climate coalition. Formally, OPEC's best response towards any carbon tax and the climate coalition's optimal carbon tax read

$$\max_p \pi(p, t) \Leftrightarrow p^o(t) = (1/2)(a - t) \quad (6)$$

$$\max_t W(R(p^o(t) + t), p^o(t)) \Leftrightarrow t^o = \psi + (1/3)(a - \psi). \quad (7)$$

The optimal carbon tax t^o is higher than the Pigouvian tax $t_P = \psi$ because the climate coalition does not only internalize the environmental damage, but also appropriates some of OPEC's monopolistic rent by raising the tax above the Pigouvian level.

OPEC's price reaction towards a quota $\bar{R} < R_M$ is to charge $q(\bar{R})$, implying the welfare function of the climate coalition to read⁸

$$W(\bar{R}, p^o(\bar{R})) = (1/2)\gamma\bar{R}^2 - \psi\bar{R}. \quad (8)$$

Since $(1/2)\gamma\bar{R}^2 - \psi\bar{R}$ is a convex function, the welfare maximum is a corner solution (either 0 or R_M) that leads to strictly lower welfare levels relative to the tax solution. This result was already pointed out by Strand (2009). However, this conclusion may not hold true in the presence of small competitive oil suppliers.

3.2 The impact of the competitive fringe

Carbon taxes

In the absence of the competitive fringe, OPEC can always charge its optimal price $p^o(t) = (1/2)(a - t)$. However, the small competitors may restrict OPEC's price setting behavior to the extent that they prevent OPEC from setting $p^o(t)$ if their marginal extraction costs are below that price, i.e. if $c < (1/2)(a - t)$. In this case, OPEC would

⁸For any $\bar{R} > R_M$, OPEC optimally reduces its supply to R_M and charges $q(R_M)$, thereby making \bar{R} redundant.

face no demand at $p^o(t)$ because the competitors would supply oil at a lower price c .⁹ Anticipating this, OPEC optimally reduces its price to c , implying the best reaction to be

$$p^*(t) = \begin{cases} (1/2)(a-t) & \text{if } c \geq (1/2)(a-t) \\ c & \text{if } c < (1/2)(a-t). \end{cases} \quad (9)$$

This function alters the welfare maximization problem of the climate coalition from equation (7) by substituting $p^*(t)$ for $p^o(t)$. As before, when the climate coalition anticipates OPEC to set $p^*(t) = (1/2)(a-t)$, i.e. when the fringe's extraction costs are sufficiently high, it is welfare-optimal to implement t^o . However, for low extraction costs, OPEC cannot charge the monopolistic price and the climate coalition anticipates OPEC to choose $p^*(t) = c$. Since OPEC cannot exert its market power, the climate coalition is unable to capture some of OPEC's rent by setting the carbon tax strategically, implying the welfare-optimal tax to be the Pigouvian tax t_P . For moderate extraction costs, i.e. for $c \in [(1/3)(a-\psi); (1/2)(a-\psi)]$, I show in the Appendix that the climate coalition can implement either t_P or t^o . The welfare-maximizing taxation strategy finally depends on the fringe's extraction costs and is reported in Proposition 1.

Proposition 1

Let $c_t \equiv (1/3)(3 - \sqrt{3})(a - \psi)$. Depending on the marginal extraction costs of the competitors c , the climate coalition's optimal tax strategy is given by

$$t^*(c) = \begin{cases} t_P = \psi & \text{if } c \leq c_t \\ t^o = \psi + (1/3)(a - \psi) & \text{if } c > c_t. \end{cases} \quad (10)$$

Proof. See Appendix. □

⁹Implicitly, I assume the competitive fringe to be large enough to supply all oil which is a reasonable assumption given the abundance of shale-oil reserves in the world. Graphically, the existence of the small competitors alter OPEC's marginal revenue to the extent that the marginal revenue equals c as long as the net oil price $q(R) - t$ is above c and drops to $MR(t)$ afterward.

The intuition behind Proposition 1 is the following.¹⁰ Choosing $t^o > \psi$ reduces the total oil consumption and therefore the consumer surplus excessively, but enables the climate coalition to appropriate some monopolistic rent. Since t^o does not depend on the size of c , a decline of the marginal extraction costs does not affect the tax level and thus the welfare of this strategy. In contrast, setting the Pigouvian tax perfectly internalizes the environmental damage and induces OPEC to charge a price of c . A decline of c then shifts a part of OPEC's profits to the consumers of the climate coalition. This increases the consumer surplus and thus the climate coalition's welfare, implying the implementation of the Pigouvian tax to become relatively more attractive as c decreases.

The interpretation of Proposition 1 is straightforward. As the marginal extraction costs of OPEC's competitors decline, e.g. due to technological progress in the shale-oil industry, the climate coalition may eventually switch from a rent-extraction strategy to a pure Pigouvian strategy when maximizing its welfare. In fact, the extraction costs of the major shale-oil fields almost halved between the years 2014 and 2016 according to Rystad Energy (2016). Thus, if the climate coalition was to use a carbon tax, it would become more likely that this tax corresponds to the Pigouvian tax that does not contain a mark-up to extract some rent from OPEC.

Quantity regulation

As in the case of taxation, the existence of the competitive fringe limits OPEC's price setting behavior. OPEC's reaction for a given quota \bar{R} is illustrated in Figure 2.

¹⁰Note that the qualitative result of Proposition 1 and all following Propositions can also be shown when using a general utility function.

Figure 2: OPEC's price reaction in the presence of a competitive fringe

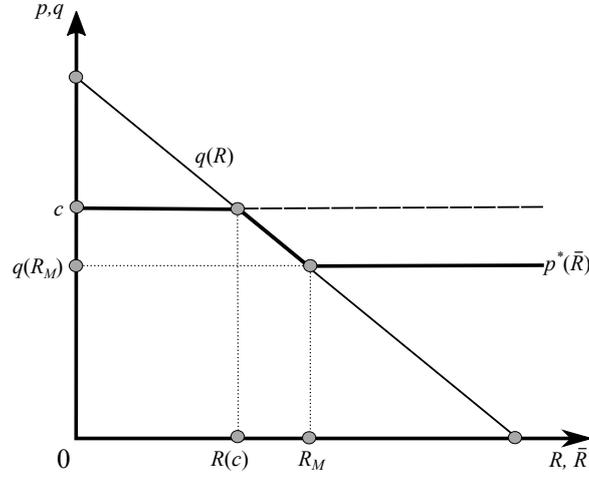


Figure 2 illustrates the inverse demand function $q(R)$, the supply function of the competitive fringe $c > q(R_M)$ and OPEC's optimal price $p^*(\bar{R})$. The reaction of OPEC towards an emissions cap \bar{R} can be divided into three intervals. As in the previous section, OPEC reduces its supply to the quantity R_M , leading to an exporter price of $q(R_M)$ for $\bar{R} > R_M$, whereas OPEC marginally undercuts the quota, which implies the exporter price to be $q(\bar{R})$ if $\bar{R} \in [R(c), R_M]$. However, for $\bar{R} < R(c)$, OPEC also marginally undercuts \bar{R} and would like to set $q(\bar{R})$, but cannot do so because the competitive fringe prevents OPEC from charging $q(\bar{R}) > c$. Hence, OPEC's profit maximizing strategy is to supply \bar{R} at a price of c . This implies the permit price to be $q(\bar{R}) - c > 0$ in this interval, leaving some carbon revenue for the climate coalition.

If the marginal extraction costs were below $q(R_M)$, OPEC would optimally charge a price of c for all \bar{R} . In summary, OPEC's price setting behavior is characterized by

$$p^*(\bar{R}) = \begin{cases} q(\bar{R}) & \text{if } \bar{R} \in [R(c), R_M] \text{ and } c \geq q(R_M) \\ q(R_M) & \text{if } \bar{R} > R_M \text{ and } c \geq q(R_M) \\ c & \text{else,} \end{cases} \quad (11)$$

while the corresponding quantities are given by

$$R^*(\bar{R}) = \begin{cases} R_M & \text{if } \bar{R} > R_M \text{ and } c \geq q(R_M) \\ \bar{R} & \text{else.} \end{cases} \quad (12)$$

The climate coalition takes the price and quantity setting behavior of OPEC into account and maximizes

$$\max_{\bar{R}} W(R^*(\bar{R}), p^*(\bar{R})) \quad \text{s.t.} \quad \bar{R} \geq 0 \quad (13)$$

For $c < q(R_M)$, OPEC always charges an oil price of $p^*(\bar{R}) = c$, implying the climate coalition to choose the quota such as to equalize the marginal utility with the social marginal costs, i.e. the marginal environmental damage plus the oil price. The optimal quota is given by

$$\bar{R}^* = \max\{(1/\gamma)(a - c - \psi); 0\}. \quad (14)$$

If $a \leq c + \psi$, i.e. if the marginal utility of the first unit of oil does not exceed the social marginal costs, then the climate coalition optimally implements a quota of zero. For $a > c + \psi$, the optimal quota \bar{R}^* is equivalent to the quantity that results from implementing the Pigouvian tax t_P and it turns out that also the permit price $q(\bar{R}^*) - c$ exactly equals t_P . Thus, both the allocation and the rent distribution are identical for both market-based instruments as long as c is not too large. However, for $c \geq q(R_M)$, the climate coalition may prefer to pursue another strategy, namely to implement a quota of R_M . To see this, consider Figure 3.

Figure 3: Optimal choice of the cap

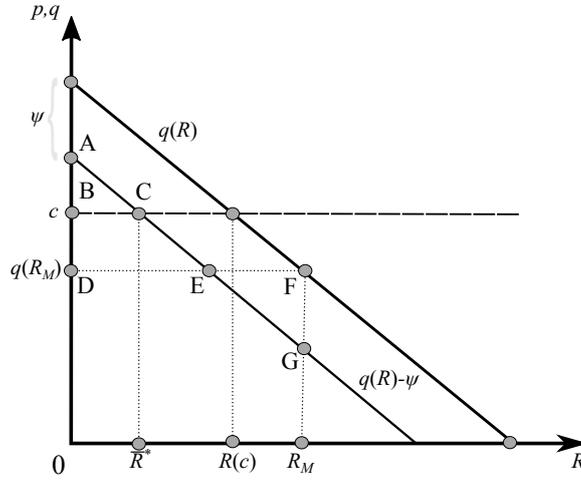


Figure 3 depicts the inverse demand function $q(R)$, the inverse demand function less the environmental damage $q(R) - \psi$, the marginal extraction costs $c > q(R_M)$ as well as the two potential strategies of the climate coalition \bar{R}^* and R_M . The climate coalition chooses \bar{R}^* such that the marginal utility net of the marginal environmental damage $q(R) - \psi$ equals the oil price c . In this case, the welfare is equal to the area of the triangle ABC. As c becomes larger, the area of the triangle ABC and thus the welfare of this strategy declines. Then, the climate coalition may prefer to choose R_M , which leads to an oil price of $q(R_M)$ and yields a welfare of ADE minus EGF. Setting $\bar{R} \in (\bar{R}^*; R_M)$ cannot be welfare-optimal. First, for an increase of \bar{R} beyond \bar{R}^* , the oil price c exceeds the marginal utility net of the marginal environmental damage. Second, in the interval $[R(c), R_M]$, the welfare function is convex due to the same reasons as pointed out in the previous section, leaving the corner solutions R_M and $R(c)$ as potential welfare maxima in that interval. However, $R(c)$ cannot be optimal because \bar{R}^* yields a strictly higher welfare level than $R(c)$, so that the climate coalition's optimal quota is either \bar{R}^* (for rather low c) or R_M (for high c). Proposition 2 reports the climate coalition's optimal

quota strategy.

Proposition 2

Let $c_q \equiv a - \psi - (1/2)\sqrt{(a - 4\psi)a}$. Depending on the marginal extraction costs c , the climate coalition's optimal quota is given by

$$\bar{R}^*(c) = \begin{cases} R_M = (1/2\gamma)a & \text{if } c \geq c_q \text{ and } a - 4\psi \geq 0 \\ \bar{R}^* = \max\{(1/\gamma)(a - c - \psi); 0\} & \text{else.} \end{cases} \quad (15)$$

Proof. See Appendix. □

If $a - 4\psi < 0$, the climate coalition's welfare when choosing R_M would be negative and therefore welfare inferior relative to choosing a zero quantity that yields a welfare level of zero. For $a - 4\psi \geq 0$, the intuition behind Proposition 2 is that for c sufficiently high, the climate coalition would optimally set \bar{R}^* so low (or even equal to zero) such that there is virtually no consumer surplus anymore. Setting the quota R_M instead implies a drop of the permit price from ψ to zero, but yields a higher consumer surplus, causing this alternative to be more favorable for large c .

In summary, the existence of the competitive fringe limits the market power of OPEC and alters OPEC's best response towards a given quota. For low extraction costs, this deters the climate coalition from choosing a corner solution that is welfare-inferior to the tax solution. Proposition 3 compares the carbon tax and cap-and-trade system for different intervals of c , assuming the climate coalition's welfare to be non-negative when choosing a quantity of R_M , i.e. assuming $a - 4\psi \geq 0$.¹¹

¹¹The consequences of relaxing this assumption are discussed further below.

Proposition 3

Let $c_t \equiv (1/3)(3 - \sqrt{3})(a - \psi)$ and $c_q \equiv a - \psi - (1/2)\sqrt{(a - 4\psi)a}$ be the threshold values for switching the policy strategy in the case of tax and quantity regulation and assume $a - 4\psi \geq 0$. Depending on the marginal extraction costs of the competitive fringe, the optimal tax $t^*(c)$, the permit price $q(\bar{R}^*(c)) - p^*(\bar{R}^*(c))$, the net oil prices $p^*(t^*(c))$ and $p^*(\bar{R}^*(c))$, the oil quantity $R(p^*(t^*(c)) + t^*(c))$, and the optimal quota $\bar{R}^*(c)$ as well as the comparisons between the climate coalition's welfare levels and OPEC's profits are given by the following table:

Table 1: Comparison of instruments

	Variable	$c \leq c_t$	$c \in (c_t, c_q)$	$c \geq c_q$
Tax	Carbon tax	ψ	$\psi + (1/3)(a - \psi)$	$\psi + (1/3)(a - \psi)$
	Oil price	c	$(1/3)(a - \psi)$	$(1/3)(a - \psi)$
	Quantity	$(1/\gamma)(a - c - \psi)$	$(1/3\gamma)(a - \psi)$	$(1/3\gamma)(a - \psi)$
Quota	Permit price	ψ	ψ	0
	Oil price	c	c	$(1/2)a$
	Quantity	$(1/\gamma)(a - c - \psi)$	$(1/\gamma)(a - c - \psi)$	$1/(2\gamma)a$
Comparison	Welfare	$W_{Tax} = W_{Quota}$	$W_{Tax} > W_{Quota}$	$W_{Tax} > W_{Quota}$
	Profit	$\pi_{Tax} = \pi_{Quota}$	$\pi_{Tax} \lesseqgtr \pi_{Quota}$	$\pi_{Tax} < \pi_{Quota}$

Proof. See Appendix. □

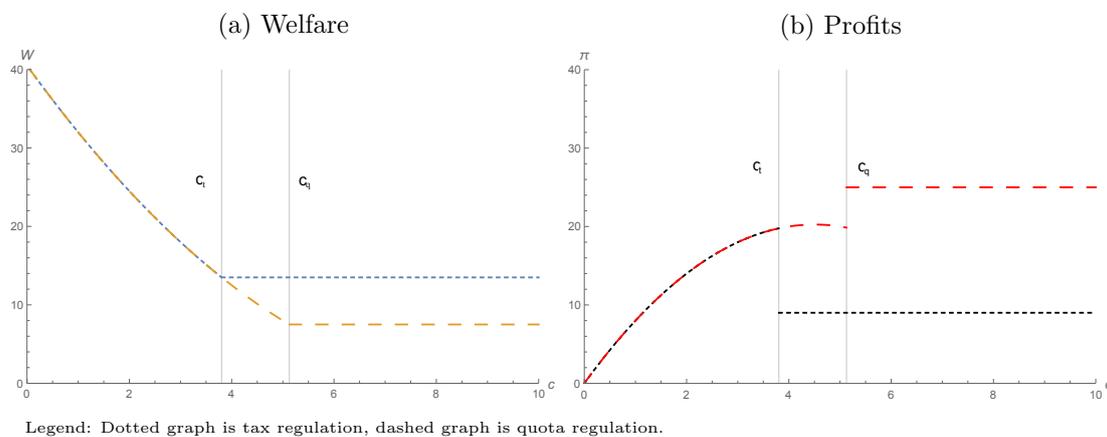
Proposition 3 shows that a carbon tax is welfare-superior to a cap-and-trade system, but that both instruments are equivalent for $c \leq c_t$, which is the main result of the present paper. The reason is that the competitors with low marginal extraction costs restrict OPEC's price setting behavior, forcing OPEC to set its oil price equal to the fringe's costs, which finally prevents OPEC from exerting its market power. By anticipating this, the climate coalition sets the levels of its instrument as if there was perfect competition in the oil market, causing both instruments to be equivalent. Thus, in the presence

of a competitive fringe with low marginal extraction costs, the result of Strand (2009) does not hold anymore. However, for $c > c_t$, OPEC can exert its market power and the climate coalition is strictly better off when using a price rather than a quantity instrument. Relative to a tax, cap-and-trade allows OPEC to extract a larger share of the climate rent. However, this does not imply that OPEC's profits are generally higher under quantity regulation because the climate coalition may optimally set a very low quota. In this case, the climate coalition's welfare as well as OPEC's profit approach zero and both players are better off under tax regulation. For $c \geq c_q$, OPEC strictly prefers quantity regulation, whereas the climate coalition is better off under tax regulation provided that $a - 4\psi \geq 0$. Remember that for $a - 4\psi < 0$, it will never be beneficial for the climate coalition to set a quota equal to the monopolistic quantity, so that the second column of Table 1 remains valid also beyond c_q .¹²

Numerical example

Figure 4 uses a numerical example with $a = 10$, $\psi = 1$ and $\gamma = 1$ to illustrate the climate coalition's welfare and OPEC's profits depending on c .

Figure 4: Comparison of tax and quantity regulation



¹²For $c \geq a - \psi$, the climate coalition optimally implements a quota of zero. In this case, a marginal increase of \bar{R} from zero would induce OPEC to charge a price of $q(0) = a$ as long as $c \geq a$, which implies the permit price to be zero. If $a - \psi \leq c < a$, then OPEC can charge c at most and the permit price would be $q(0) - c = a - c$ in this case.

In the interval $c \leq c_t$, both regulations are equivalent. Since the costs for oil of the climate coalition respectively the oil revenue of OPEC are increasing in c , the consumer surplus and thus the welfare are decreasing, whereas profits are increasing in c . Beyond c_t the climate coalition switches its tax strategy from t_P towards t^o so that OPEC charges a price that only depends on the tax level, but not on c , implying both welfare and profit to remain constant. For $c > c_q$, the climate coalition optimally chooses a quota of R_M , which is why the welfare and the profit under quantity regulation do not change in this interval. Note that the climate coalition is strictly better off under a carbon tax for $c > c_t$, whereas OPEC's profit is lower when facing carbon taxation relative to a quota.

4 Quantity regulation with base tax

In order to retain some of the carbon revenue, Schöb (2010) proposes to complement the cap-and-trade system by levying a base tax, i.e. a per unit tax on the consumption of the resource. This proposal is analyzed in the following. When the climate coalition implements a quota \bar{R} with a base tax t_b , Figure 5 illustrates OPEC's reaction in the absence of the competitive fringe.

Figure 5: OPEC's reaction towards the dual instrument

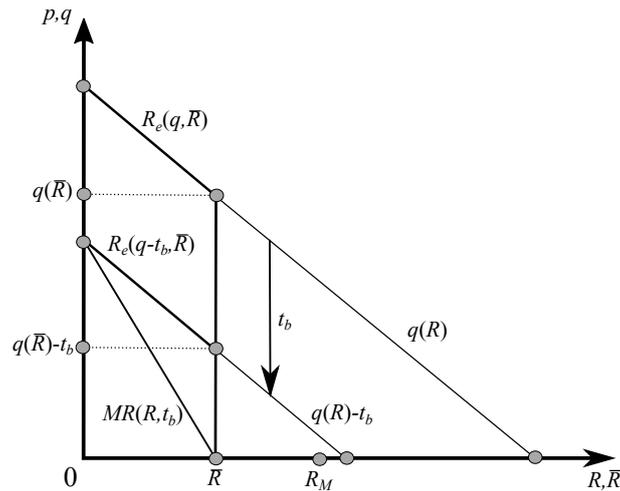


Figure 5 shows the quota \bar{R} , effective demand functions $R_e(q, \bar{R})$ and $R_e(q - t_b, \bar{R})$ as well as the marginal revenue $MR(R, t_b)$. Abstracting from the base tax, OPEC's best reaction towards any quota $\bar{R} \leq R_M$ is to charge $q(\bar{R})$. Complementing the quota \bar{R} with a base tax t_b forces OPEC to reduce its oil price from $q(\bar{R})$ to $q(\bar{R}) - t_b$ and allows the climate coalition to appropriate a part of the climate rent equal to $t_b \cdot \bar{R}$.

Suppose that \bar{R} was the optimal quota, then the climate coalition can do no better than setting t_b . Any base tax below t_b would yield the same oil consumption, but a lower carbon revenue. Setting the base tax above t_b leads OPEC to reduce its supply to some $R < \bar{R}$, which is welfare-inferior because \bar{R} was assumed to be the optimal quota. Thus, for any given quota $\bar{R} \leq R_M$, there is exactly one optimal complementary base tax, which should be chosen such that the marginal revenue of OPEC equals zero at \bar{R} . Formally, the one-to-one relationship between quota and optimal base tax results from the profit maximization of OPEC, which is given by

$$\frac{\partial \pi(R, t_b)}{\partial R} = MR(R, t_b) = a - t_b - 2\gamma R \stackrel{!}{=} 0 \quad \Leftrightarrow \quad R^o(t_b) = (1/2\gamma)(a - t_b). \quad (16)$$

Putting it differently, in order to implement any desired quantity, the climate coalition only needs to set the base tax accordingly. This result also holds true in the presence of the competitive fringe. In this case, OPEC's profit maximizing quantity when facing a base tax only is given by¹³

$$R^*(t_b, c) = \begin{cases} (1/2\gamma)(a - t_b) & \text{if } c \geq (1/2)(a - t_b) \\ (1/\gamma)(a - c - t_b) & \text{if } c < (1/2)(a - t_b). \end{cases} \quad (17)$$

The climate coalition can induce OPEC to supply any desired quantity by choosing the base tax appropriately. More importantly, the climate coalition cannot improve its welfare by choosing a quota other than $R^*(t_b, c)$. Setting a quota $\bar{R} > R^*(t_b, c)$ makes

¹³This follows from equations (9) and (4).

this quota redundant because OPEC's actual supply is lower. On the other side, if a quota $\bar{R} < R^*(t_b, c)$ was optimal for the climate coalition, then the climate coalition could achieve a higher welfare level by increasing the base tax such that OPEC indeed supplies \bar{R} . By doing this, the climate coalition appropriates a larger share of OPEC's rent while consuming the same quantity \bar{R} . In summary, also in the presence of a competitive fringe, there is a one-to-one relationship between the base tax and OPEC's oil supply. To implement the welfare maximizing quantity, the climate coalition only needs to set the base tax appropriately and cannot improve its welfare by choosing a quota other than OPEC's profit maximizing oil supply. Proposition 4 reports the implication of this finding.

Proposition 4

The quantity regulation with a complementary base tax is equivalent to the tax regulation.

Proof. Follows immediately from the one-to-one relationship between the base tax and OPEC's profit maximizing oil supply. □

Proposition 4 shows that by using a cap-and-trade system that is complemented by the optimal base tax, the climate coalition is neither worse off nor better off relative to the use of a carbon tax. The reason is that once the base tax is set optimally, the climate coalition cannot increase its welfare when setting a quota other than OPEC's profit maximizing oil supply.

5 Conclusion and discussion

This paper analyzes the impact of declining extraction costs of the competitive fringe on the choice of the climate policy instrument in a strategic game between a climate coalition and a dominant oil supplier such as OPEC. I show that, from the perspective

of the climate coalition, a pure cap-and-trade system turns out to be weakly welfare-inferior relative to a carbon tax, while a cap-and-trade system that is accompanied by a base tax is equivalent to a carbon tax.

The marginal extraction costs of the competitive fringe constitute an upper bound for the price, OPEC can charge and thus impact the climate coalition's optimal tax strategy. High extraction costs allow OPEC to exert its market power and to charge the monopolistic price. Anticipating this, the climate coalition chooses a tax that both extracts some of OPEC's monopolistic rent and accounts for the damage from global warming. However, low marginal extraction costs prevent OPEC from exerting its market power, causing the climate coalition to optimally set the Pigouvian tax.

Relative to a carbon tax, a cap-and-trade system enables OPEC to extract a larger share of the climate rent by marginally undercutting the climate coalition's quota. Since the oil price cannot exceed the fringe's marginal extraction costs, lower costs limit the rent extraction of OPEC, leaving more revenue for the climate coalition. If the marginal extraction costs are sufficiently low, then the climate coalition will optimally choose the quota that is equivalent to the quantity that would have resulted from implementing the Pigouvian tax, implying both instruments to be equivalent.

The findings of this paper suggest that in the presence of a dominant oil supplier that faces competition from small oil extractors with higher extraction costs, a carbon tax should be preferred over a cap-and-trade system, confirming the implications of earlier papers such as Berg et al. (1997), Strand (2011), Wirl (2012) and Strand (2013). In fact, there are many other economic arguments, including lower administration costs or the absence of carbon price volatility, for why carbon taxes are superior to cap-and-trade. This superiority suggests that in the international climate negotiations in the coming years, the conference of the parties should rather aim at establishing a common carbon price than at negotiating country-specific emissions reduction targets. However, in the Paris Agreement, the conference of the parties committed themselves to fixed emissions

reduction targets. Even though it remains to be seen which policy instrument each country will finally implement, it seems to be likely that cap-and-trade will turn out as the predominant climate policy instrument.

The political preference for cap-and-trade relative to carbon taxes originates primarily from two reasons. First, climate science suggests the existence of tipping points, i.e. dramatic, discontinuous, and irreversible changes of the climate system that occur after passing certain temperature or emissions concentration thresholds. Given the uncertainty about the marginal abatement costs, imposing adequate quotas guarantees to avoid passing these thresholds, while carbon taxes do not. Second, carbon taxes seem to lack political support at a national level in some major emitting countries such as the United States, where the political climate is characterized by a general resistance to any new taxes. In contrast, launching emissions trading schemes is likely to come along with a generous allocation of free emissions certificates for the regulated industries, which reduces the compliance costs. While firms bear both the abatement costs and the tax payments when facing a carbon tax, they incur only the abatement costs in the case of a cap-and-trade that allocates the allowances free of charge. This makes the private sector and the special interest groups less likely to oppose a cap-and-trade system relative to a carbon tax.

Provided that carbon taxes are politically not feasible, so that the conference of the parties needs to agree on quantities, the policy implication of this paper is that the quantity regulation should be complemented by levying a base tax. The base tax redistributes some rent from OPEC as tax revenues to the governments of the climate coalition, which potentially could pass the revenue on to the regulated firms. If the implementation of a base tax was politically not feasible, the climate coalition could accompany the cap-and-trade system by a floor price instead. A floor price is formally equivalent to a base tax and thus also guarantees the appropriation of some rent from OPEC. The regulated industries could be compensated by allocating a substantial share

of allowances free of charge, making the ratification at the national level more likely.

Future research could, firstly, incorporate more than one fuel, e.g. oil and natural gas or coal, as partly done by Berger et al. (1992) and Strand (2011). Their analyses indicate that the (uncorrelated) demand for the second fuel and thus for emissions allowances limits OPEC's rent extraction in a cap-and-trade system. Secondly, the model employed in the present paper is static, whereas the extraction of exhaustible resources is inherently a dynamic problem. Thus, a possible extension would analyze the research question of this paper within a two-period model in analogy to the framework of Eichner and Pethig (2011).

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A Appendix

Proof of Proposition 1

First, I show that for $c \in [(1/3)(a - \psi), (1/2)(a - \psi)]$ the climate coalition can either implement $t_P = \psi$ or $t^o = \psi + (1/3)(a - \psi)$. If the climate coalition sets t^o , then OPEC indeed chooses $p^*(t^o) = (1/2)(a - t^o) = (1/3)(a - \psi)$ as long as $c \geq (1/3)(a - \psi)$. If the climate coalition sets t_P , then OPEC cannot implement its profit maximizing price $p^*(t_P) = (1/2)(a - t_P) = (1/2)(a - \psi)$ for $c \leq (1/2)(a - \psi)$. Hence, if $c \in [(1/3)(a - \psi), (1/2)(a - \psi)]$, then the climate coalition can implement either t_P or t^o . The respective welfare levels are given by

$$W(R(p^*(t^o) + t^o), p^*(t^o)) = (1/6\gamma)(a - \psi)^2 \quad (\text{A.1})$$

$$W(R(c + \psi), c) = (1/2\gamma)(a - c - \psi)^2. \quad (\text{A.2})$$

It follows that $(1/2\gamma)(a - c - \psi)^2 \geq (1/6\gamma)(a - \psi)^2$ as long as $c \leq (1/3)(3 - \sqrt{3})(a - \psi) \equiv c_t$ which proofs Proposition 1.

Proof of Proposition 2

Depending on c , the climate coalition either sets $\bar{R}^* = \max\{(1/\gamma)(a - c - \psi); 0\}$ or $R_M = (1/2\gamma)a$. The respective welfare levels are given by

$$W(R^*(\bar{R}^*), p^*(\bar{R}^*)) = \begin{cases} (1/2\gamma)(a - c - \psi)^2 & \text{if } c \leq a - \psi \\ 0 & \text{if } c > a - \psi \end{cases} \quad (\text{A.3})$$

$$W(R^*(R_M), p^*(R_M)) = (1/8\gamma)(a - 4\psi)a. \quad (\text{A.4})$$

Note that $W(R^*(R_M), p^*(R_M))$ is positive for $a - 4\psi \geq 0$ and thus welfare-superior to $\bar{R}^* = 0$. The quota R_M is welfare-superior to $\bar{R}^* > 0$ as long as $(1/8\gamma)(a - 4\psi)a \geq$

$(1/2\gamma)(a - c - \psi)^2$, which holds true for $c \geq a - \psi - (1/2)\sqrt{(a - 4\psi)a} \equiv c_q$. This proves Proposition 2.

Proof of Proposition 3

The first three lines of Table 1 follow from the proof of Proposition 1 and from equations (4) and (9). The lines four to six are proved by the proof of Proposition 2, equations (11) and (15) as well as the fact that the permit price is given by $q(\bar{R}^*(c)) - p^*(\bar{R}^*(c))$.

For the seventh line, the first two entries immediately follow from the proof of Proposition 1. Using (A.1) and (A.4) and noting that $(1/6\gamma)(a - \psi)^2 > (1/8\gamma)(a - 4\psi)a$ proves the last entry.

For the last line, we have

$$\pi(p = c, t = \psi) = (1/\gamma)(a - c - \psi)c \quad (\text{A.5})$$

$$\pi(p = (1/3)(a - \psi), t = \psi + (1/3)(a - \psi)) = (1/9\gamma)(a - \psi)^2 \quad (\text{A.6})$$

$$\pi(p = (1/2)a, t = 0) = (1/4\gamma)a^2 \quad (\text{A.7})$$

The first entry of the last line is obvious. For the third entry, we have $(1/4\gamma)a^2 > (1/9\gamma)(a - \psi)^2$. For the second entry, note that $\pi(p = c, t = \psi)$ approaches zero when c approaches $a - \psi$, implying $\pi(p = (1/3)(a - \psi), t = \psi + (1/3)(a - \psi)) > \pi(p = c, t = \psi)$. However, the opposite holds true at, e.g. $c = c_t$, where $\pi(p = c, t = \psi)|_{c=c_t} - \pi(p = (1/3)(a - \psi), t = \psi + (1/3)(a - \psi))|_{c=c_t} = (1/9\gamma)(3\sqrt{3} - 1)(a - \psi)^2 > 0$, which proves the ambiguous relation sign in the second entry of the last line.

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