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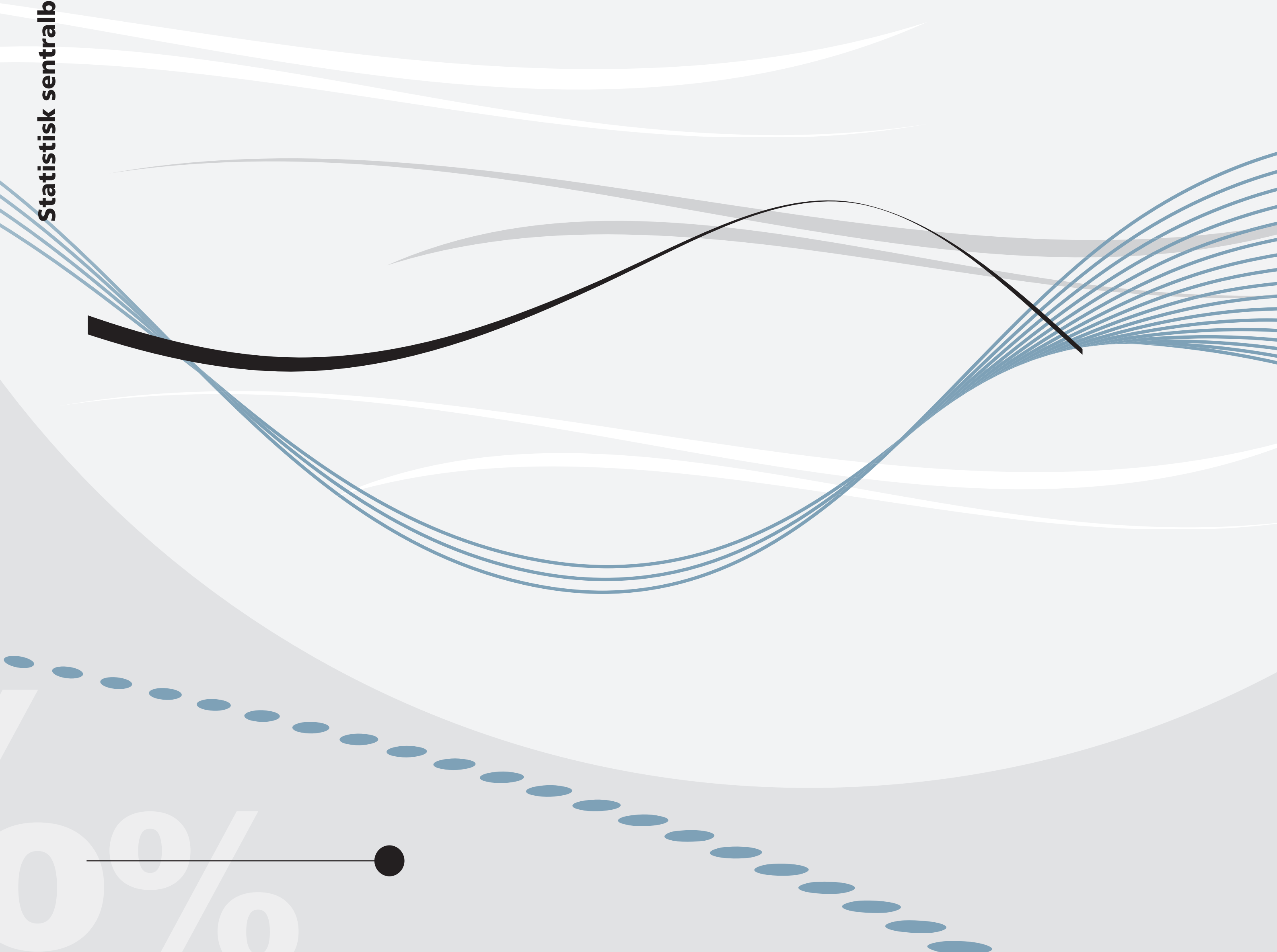

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Abstract:
In a non-renewable resource market with imperfect competition, the resource owners' supply is governed both by current demand and by the resource rent. New information regarding future market conditions will typically affect the resource rent and hence current supply. Bleaker prospects will tend to accelerate extraction. We show, however, that for resource owners with substantial resource stocks, a more pessimistic outlook may in fact slow down early extraction. The explanation is that for players with extensive resource stocks, the resource rent is limited and supply is more driven by current market considerations. As players with less resources accelerate their supply, it may be optimal for the large resource owners to cut back on their supply. We illustrate this in the case of the European gas market, finding that the shale gas revolution may lead to an accelerated supply by most gas producers, but a postponement of Russian gas extraction.

Keywords: Exhaustible Resource Extraction, Cournot Competition, Natural Gas.

JEL classification: Q31, Q41, D43.

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Sammendrag

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1 Introduction

The European gas market has for decades been dominated by the supply from five large gas producing countries, i.e., Russia, Norway, the UK, the Netherlands and Algeria. Since the early 1980's these countries have jointly accounted for two thirds or more of total gas supply to the European Union. As a consequence, the European gas market has usually been modelled as a Cournot game in the economics literature (see, e.g., Golombek et al., 1995, 1998; Holz et al., 2008, 2009; Zwart, 2009).

The resource bases of the five mentioned countries are very heterogeneous, however, and their gas supply have developed quite differently. Whereas UK gas production in 2011 was 60% below its peak supply in 2000, Russian and Algerian gas production and exports to Europe are expected to increase over the next couple of decades (see e.g. IEA, 2012). This difference reflects to a large degree that the reserve-to-production ratio (R/P-ratio), i.e., remaining reserves divided by current annual production, are very different for the five countries. According to BP (2012), Russia and Algeria have R/P-ratios of 74 and 58 years, respectively, while the figure for the UK is merely 4.5 years. Norway and the Netherlands are in between with with R/P ratios of 20 and 17 years, respectively. As reserves can be increased through exploration and technical improvements, the R/P-ratios should not be taken too literally.[1] Still, the figures clearly show that the five countries are in quite different positions with respect to future market influence.

This heterogeneity points to the fact that natural gas is a non-renewable resource. That is, gas resources extracted today cannot be extracted in the future. Hence, gas resource owners should consider the optimal path for extraction of their resources. Intuitively, the optimal extraction path for a resource owner depends on how market conditions develop over time. Thus, a substantial shift in expectations about future supply or demand will tend to change the optimal extraction path, and is therefore expected to affect current extraction as well. A recent example of such a shift in expectations is the shale gas revolution in the United States (see e.g. IEA, 2012, and Gabriel et al., 2013). Substantial cost reductions in extracting shale gas have significantly altered the expectations

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[1] In fact, remaining gas reserves in Russia *increased* from 2001 to 2011, and decreased far less than accumulated extraction over this period in Algeria and Norway.

about future gas production in the U.S. (see e.g. the totally different trade projections for the U.S. in EIA, 2007 and EIA, 2012).

In this paper we investigate how altered expectations regarding future market conditions affect current supply in a non-renewable resource market characterized by oligopolistic competition. Although we mainly have the European gas market in mind, our study is also relevant for other non-renewable markets with imperfect competition such as the global oil market. In line with previous studies of the European gas market, we assume Cournot competition between the largest suppliers to this market.

If new information arrives about less demand or more supply in the future from other sources, the producers will as a first response shift some of its extraction towards the present as future profitability declines. This is intuitive, and is also the core of the so-called Green paradox literature (e.g., Sinn, 2008, Gerlagh, 2010, and Hoel, 2010).

We are, however, particularly interested in whether heterogeneity with respect to remaining reserves has a bearing on the response of the individual producer. First, we analyze this question using a theoretical model with two Cournot producers that differ with respect to reserve levels. We find that although total supply will go up initially, this is not necessarily the case for the individual producer. If one producer has a sufficiently large share of remaining reserves, we show that initial supply from this producer will drop when future market considerations become less profitable. The reason is that current supply from a producer with large reserves is driven more by the current market condition and less by the resource rent. Hence, when the other producer moves its extraction towards the present, it becomes optimal for the producer with large reserves to cut back on its own early extraction.

We next construct a dynamic numerical model for the European gas market, and analyze how new information about future unconventional gas supply may change the current market. Our simulation results suggest that this will lead to higher initial gas supply from all Cournot producers but Russia, who reduces its exports to Europe. As indicated above, Russia has vast reserves of gas. According to BP (2012), Russia's remaining reserves are almost six times higher than the combined reserves of the five other big suppliers to the European market referred to above. A major share of Russian gas production is consumed domestically though, but natural gas is hardly a scarce resource in Russia. Thus, there is little need for Russia to curb its current extraction in order to save more resources for the future, and they act almost like a static Cournot player in the model. Hence, when other gas producers increase their initial supply, Russia cuts back.

Our results imply that the production profile of heterogeneous firms may be very differently affected by changes in future demand under oligopoly. This could be particularly relevant for policy if the government cares about the composition of supply. For example, policies that reduce future demand for gas (e.g., subsidies to development of renewable energy) may alleviate current European dependence on gas imports from Russia.[2] Moreover, we find that Cournot competition in strategic substitutes induces the Cournot firms to moderate the increase in aggregate current production induced by bleaker future prospects, as compared to a resource market with competitive firms. This suggests that market power may alleviate (but not remove) the green paradox, because the increase in early production and emissions caused by lower future demand is dampened.

The economics literature on optimal extraction of non-renewable resources goes back to the seminal paper by Hotelling (1931), who concluded that the price of the resource would increase with the interest rate. Of particular relevance to the present paper is the theory of 'oil'igopoly developed by Salant (1976). By taking a dynamic Nash-Cournot approach to model the oil market, Salant (1976) captured two aspects that are central in many resource markets: imperfect competition and exhaustible resources. The theory of 'oil'igopoly has later been extended by Loury (1986), and Polasky (1992) who also found empirical support for the predictions of the theory using data on proved reserves and production in a cross-section of oil exporting countries. More recently, Boyce and Voitassak (2008) examined a model of 'oil'igopoly featuring exploration of new reserves. They find that firms holding smaller proved reserves should be observed doing more research, and claims that this prediction is consistent with country-level production and reserve data in the post-World War II era. Another strand of literature relevant to the present paper examines current effects of changes in future values of resource stocks. This may either be caused by future competition (e.g. a backstop technology) or policy changes, see e.g. Heal (1976) and the green paradox literature cited above. Finally, Chakravorty et al. (2011) show that when technological progress in an alternative energy source

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[2] European dependence on Russian gas is discussed at: http://www.heritage.org/research/reports/2009/01/europe-should-reduce-dependence-on-russian-energy-and-develop-competitive-energy-markets.

can occur through learning-by-doing, resource owners face competing incentives to extract rents from the resource and to prevent expansion of the new technology. It is then not necessarily the case that scarcity-driven higher traditional energy prices over time will induce alternative energy supply as resources are exhausted.

2 Theoretical analysis

This section considers a decline in the residual demand for the firms' joint resource production at time $t' \in [T, T']$, with $T' > T$ and under the assumption that both firms produce at time t'.[3] The model is formulated in continuous time, but to simplify the exposition we divide the time of analysis into two time periods: period 1 refers to the time before the decline in demand ($t \in [0, T)$), and period 2 refers to the time after the decline in demand ($t \in [T, \infty)$).

The model assumes that there are two Cournot firms i and j, each with resource extraction flow rate at time t given by $q_{it} \geq 0$ and $q_{jt} \geq 0$, respectively. Constant marginal extraction costs are denoted c_i and c_j, whereas r refers to the discount rate. S_{it} and S_{jt} denote the finite resource stocks of the firms at time t and the resource price is $p_t = K_\tau - q_{it} - q_{jt}$, with subscript $\tau = 1, 2$ referring to the two time periods. We assume that marginal costs are less than the choke price ($K_\tau > c_i, c_j$). The decline in future residual demand is modelled as a fall in the parameter K_2. The decline may be caused by the entry of new producers, the development of viable renewable substitutes, introduction of end-use taxes, or changes in consumer preferences. In the numerical model in Section 3 we examine the European gas market, and the decline in future residual demand is caused by shale gas development in the US. The model is best examined by backwards induction.

2.1 Production in period 2

In the second time period firm i maximizes profits:

$$\pi_i = \max_{q_{it}} \int_T^\infty e^{-rt}[(K_2 - q_{it} - q_{jt}) - c_i]q_{it}dt, \tag{1}$$

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[3] The theoretical analysis is at firm level, whereas the players are countries in the numerical model in Sections 3 and 4.

subject to the binding resource stock constraint:

$$\int_T^\infty q_{it} = S_{iT}.$$

The remaining resource stock of producer i at time t is $S_{it} = S_{iT} - \int_T^t q_{i\tau} d\tau$, which implies $\dot{S}_{it} = -q_{it}$. We observe that the profits earned in period 2 equals the salvage value of the resource at the end of period 1. It is clear from the above equations that the shadow value of the resource stock is positive for finite resource stocks ($\partial \pi_i / \partial S_{iT} > 0$) and increasing in the parameter K_2, that is, $\partial \left(\partial \pi_i / \partial S_{iT} \right) / \partial K_2 > 0$ for finite stock S_{iT}.

2.2 Production in period 1

In the first time period firm i maximizes profits:

$$\max_{q_{it}} \int_0^T e^{-rt} [(K_1 - q_{it} - q_{jt}) - c_i] q_{it} dt + \pi_i$$

subject to equation (1) and the resource constraint:

$$\int_0^T q_{it} \leq S_{i0}.$$

The current value Hamiltonian is $H = [(K_1 - q_{it} - q_{jt}) - c_i - \lambda_{it}] q_{it}$, which is concave in q_{it}. According to the Maximum principle, the profit maximizing extraction path must satisfy:

$$H_{q_t} = K_1 - c_i - 2q_{it} - q_{jt} - \lambda_{it} = 0, \tag{2}$$

$$\dot{\lambda}_{it} - r\lambda_{it} = -H_{S_{it}} = 0, \tag{3}$$

$$\lambda_{iT} = \frac{\partial \pi_i}{\partial S_{iT}}, \tag{4}$$

where equation (4) is the transversality condition. It states that the shadow price of the resource at time T must equal the marginal contribution of the resource to the salvage value $\partial \pi_i / \partial S_{iT}$. In terms of our model, the marginal discounted value of the resource must be equal across the two time periods. Otherwise, the firm could increase the present value of profits by moving resource extraction from one period to the other.

Solving the differential equation (3) we get $\lambda_{it} = Ce^{rt}$, where the constant C solves the boundary condition $Ce^{rT} = \lambda_{iT}$. Hence, we have $\lambda_{it} = \lambda_{iT}e^{r(t-T)}$. Insertion in (2) yields $K_1 - c_i - 2q_i - q_j - \lambda_{iT}e^{r(t-T)} = 0$. Solving this system of two equations, and using (4), we have:

$$q_{it} = \frac{1}{3}\left(A_i + \left(\frac{\partial \pi_j}{\partial S_{jT}} - 2\frac{\partial \pi_i}{\partial S_{iT}}\right)e^{r(t-T)}\right), \tag{5}$$

with $A_i = K_1 - 2c_i + c_j$. Differentiating with respect to the demand parameter in period 2 (K_2) we get:

$$\frac{\partial q_{it}}{\partial K_2} = \frac{1}{3}\left(\frac{\partial(\partial \pi_j/\partial S_{jT})}{\partial K_2} - 2\frac{\partial(\partial \pi_i/\partial S_{iT})}{\partial K_2}\right)e^{r(t-T)}, \tag{6}$$

Equation (6) captures two opposing effects on firm i's production caused by a reduction in future demand ($-\partial q_{it}/\partial K_2$). First, we have an *intertemporal effect* captured by the second part of the parenthesis in (6): a decline in future demand induces the resource owning firm i to increase current production. The reason is that the discounted net present value of the resource must be equalized across time, and the relative fall in future net present value of the resource, caused by the decline in future demand, can be offset by moving production from period 2 to period 1. However, for the same reason the competitor firm j also increases production in period 1. As the firms' production levels are strategic substitutes, this leads us to the second and *static effect* captured by the first part of the parenthesis in (6): when the other firm j increases current production, the product price decreases and induces firm i to produce less. This is a well known result from analysis of Cournot competition (Tirole, 1988).

In general it is ambiguous whether the intertemporal or the static effect dominates for an individual firm, but total current production must increase (because the static effect is caused by the price decrease). This is easily seen from (6), which implies that the change in aggregate production is:

$$\frac{\partial q_{it}}{\partial K_2} + \frac{\partial q_{jt}}{\partial K_2} = -\frac{1}{3}\left(\frac{\partial(\partial \pi_j/\partial S_{jT})}{\partial K_2} + \frac{\partial(\partial \pi_i/\partial S_{iT})}{\partial K_2}\right)e^{r(t-T)} < 0,$$

which is negative for finite resource stocks S_{i0} or S_{j0} (and zero if both stocks are infinite). That is, a decrease in future demand (decline in K_2) increases current aggregate production. In the particular case of identical firms, both firms will increase their production in period 1. This result is related to the Green paradox literature (see Section 1).

Assume instead that the two firms differ and, for the sake of argument, that the reserve-to-production ratio of firm i is sufficiently large that the extraction in period 1 approximately does not affect the discounted value of the remaining resource in time 2; i.e., $\partial \pi_i / \partial S_{iT} \approx 0$ (while we still have $\partial \pi_j / \partial S_{jT} > 0$). Then (6) becomes:

$$\frac{\partial q_{it}}{\partial K_2} \approx \frac{1}{3} \left(\partial \frac{\partial \pi_j / \partial S_{jT}}{\partial K_2} \right) e^{r(t-T)} > 0,$$

for firm i. It follows that firm i would reduce supply in period 1 if demand decreases in period 2 (i.e., a decrease in K_2). Obviously, as total production increases, the smaller resource stock owning firm j increases production more than firm i decreases its production:

$$\frac{\partial q_{jt}}{\partial K_2} \approx -\frac{2}{3} \left(\partial \frac{\partial \pi_j / \partial S_{jT}}{\partial K_2} \right) e^{r(t-T)} < 0.$$

The approximation $\partial \pi_i / \partial S_{iT} \approx 0$ is only reasonable for very large stock owners. If S_{i0} is not that large, the sign of $\partial q_{it} / \partial K_2$ in (6) is ambiguous.[4] We state the following result:

Proposition 1 *In a non-renewable market with two Cournot players and linear demand, a resource owner that endows a sufficiently large share of total reserves will reduce (increase) current production if future demand for the resource declines (increases).*

Proof. The Proposition follows from equation (6). ■

The result arises from the two opposing mechanisms discussed under equation (6), and the observation that firms with ample resources and thus low scarcity values care little about saving resources for future use while market power considerations remain important. Therefore, the intertemporal effect is weak and the static effect dominates for owners of sufficiently large resource stocks. Indeed, at the limit, a firm with very large resources may have approximately zero net present value of an additional unit of the resource. Such a firm does not delay any production due to scarcity considerations and only the

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[4] It can be shown that the Maximum principle leads to the equation $r\widetilde{T}_i + e^{-r\widetilde{T}_i} = 1 + 3rS_i/A_i + rT - e^{rT}$ in period 2, with $A_i = K_1 - 2c_i + c_j$. These equations do not admit analytical solutions for the optimal time horizon in period 2 ($\widetilde{T}_i$). Therefore, a reduced form solution for $\partial q_{it} / \partial K_2$ is not possible.

strategic effect matters. This firm unambiguously decreases production. We also observe that, while Salant (1976) argues that a cartel of (large) resource owners restricts its sales so as to take over the market after the competition has exhausted its reserves, Proposition 1 does not depend upon this mechanism.

Proposition 1 was derived in the case of 2 players with strict assumptions on the functional forms. However, the economic intuition behind the result suggests that it may be valid in the more general case. In this respect, it is of interest that the numerical model for the European gas market in the next section, with several Cournot players and isoelastic gas demand, indicates that the shale gas revolution will lead to accelerated supply of most gas producers, but postponement of Russian gas extraction.

3 Numerical model description

We now turn to the European gas market, and simulate the effects of a positive shift in future supply of gas to this market. A relevant interpretation here is the significant change of view over the last five years regarding the future prospects of unconventional gas. Major technological progress in hydraulic fracturing and horizontal drilling have substantially increased the expected supply of shale gas in the U.S. over the next few decades (see, e.g., Gabriel et al., 2013), and also increased unconventional supply expectations in Europe and elsewhere in the world in the longer term.

The European gas market currently has five large suppliers: Russia, Norway, the Netherlands, the UK and Algeria. In addition there is some domestic production in several other European countries, as well as relatively small imports from other parts of the world (mainly through LNG). Consistent with previous models of the European gas market (cf. Section 1), we model the large suppliers as Cournot players. The exception is the UK, where remaining reserves are low and production is not coordinated across companies.[5] To simplify, we consider supply from the UK and other smaller European producers as exogenous.[6] The

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[5] There is no explicit supply coordination among companies on the Norwegian continental shelf either. However, Norwegian authorities can to a large degree regulate the total extraction level through licensing of fields and pipelines. Moreover, Statoil has a dominating position in Norway. The Dutch authorities explicitly regulate the extraction rate of the major Groningen field.

[6] We assume that production from these countries declines by a fixed annual rate, so that accumulated production over time equal reported reserves at the end of 2009. Total supply in 2015 from these countries is then only slightly above Dutch supply in 2009. Hence, modelling this supply as competitive and not too price-responsive would not alter our results notably.

joint supply of LNG and pipeline imports from other sources than Russia and Algeria is modelled as a linear increasing function of the price. The inverse supply function is assumed to tilt downward over time, reflecting that more gas imports are expected to become available over the next few decades (cf. e.g. IEA, 2012).

As we focus on the supply side effects in the European gas market, we consider a single, representative gas consumer. We include not only EU gas consumption, but also consumption in the rest of Europe (including Ukraine and Belarus). European gas demand (D^E) is assumed to be decreasing in the gas price, but instead of a linear demand schedule as in Section 2 we assume a fixed long-run price elasticity ϵ^E (set equal to $\epsilon^E = -0.5$).[7] Over time, gas demand increases due to growth in GDP. The income elasticity is calibrated based on projections of gas consumption by the IEA (2011a).

The four Cournot players take the supply from the other players as given in their optimization problem. However, they do take into account the price effects on the demand side and on the supply of imported gas (besides Russia and Algeria). That is, they consider that an increase in production will lead to a lower gas price due to demand reactions, but the price reduction is moderated by reduced gas import. Formally, they have the following maximization problem:[8]

$$\pi_i = \max_{q_{it}} \sum_{t=0}^{T} (1+r)^{-t} \left(p_t^E(q_t) - c_{it}(A_{it}) - c_{it}^{\tau} \right) q_{it}, \tag{7}$$

subject to:

$$A_{it+1} = A_{it} + q_{it} \tag{8}$$

where A_{it} denotes accumulated production, and c_{it}^{τ} transport costs to the European market, $p_t^E(q_t)$ the residual demand schedule facing the oligolipolistic prodecers, and r is the producer discount rate. The discount rate is set to 5 percent in the simulations. Note that we do not assume a fixed resource stock as in the theoretical model. Instead we assume that unit costs are increasing in accumulated production, so that only a finite resource level will have unit extraction costs below the prevailing price at a given point in time. To be specific,

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[7] There is no clear consensus in the literature regarding direct price elasticities for natural gas (see, e.g., Andersen et al., 2011). -0.5 is well within the range of long-run estimates found in the literature.

[8] In the numerical model we simulate the market for a sufficiently high but finite number of years, T. We test the effects of changing the level of T, checking that the reported results are unaffected by the choice of T.

we assume that extraction costs develop according to the following:

$$c_{it}(A_{it}) = c_i^0 e^{\eta_i A_{it} - \theta_i t} \tag{9}$$

where we also allow for exogenous technological progress through the annual rate θ_i. c_i^0 is the initial unit extraction costs, which are based on IEA (2009). The parameter η_i is crucial because it determines how quickly unit costs rise as accumulated production increases. Intuitively, the parameter will be higher the less reserves a country has. We calibrate the parameters based on reserve data from BP (2012).[9]

From the optimization problem above we derive the following first order condition for the Cournot players:

$$c_{it}(A_{it}) + c_{it}^T + \lambda_{it} = p_t^E \cdot \left(1 + \frac{q_{it}}{\epsilon^E D^E - \kappa_t p_t^E}\right) \tag{10}$$

where λ_{it} now denotes the (positive) shadow price of the resource, and κ_t is the slope of the import supply function (which increases over time). This condition corresponds to equation (2) in Section 2, with total marginal costs (which is the marginal costs of production plus the shadow price) equal to marginal revenue.

The shadow price λ_{it} develops according to:

$$\lambda_{it} = (1 + r)\lambda_{it-1} - \eta_i c_{it}(A_{it}) q_{it} \tag{11}$$

Russia is the largest gas supplier in the European market. However, the biggest share of Russian gas production is consumed domestically. Hence, in order to model Russian gas export to Europe appropriately, we also model the Russian gas market. Gas demand in Russia is also modeled with a fixed price elasticity ϵ^R, but we assume the elasticity to be half as big as the one in Europe.[10]

Russian gas prices are highly regulated. Over the last few years, prices have

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[9] We simply assume that all reported reserves in the baseyear can be economically extracted at the baseyear price. In other words: We assume that unit costs (plus transport costs) become equal to the baseyear price when all reported reserves have been extracted (and there is no technological change). For Algeria, however, we take into account that a large share of Algerian production is consumed domestically or exported elsewhere. Thus, we reduce the reserves destined for Europe by 50%.

[10] There are few studies of Russian price elasticities for gas. Solodnikova (2003) finds no significant price effects at all, partly because a large part of Russian gas consumers is not facing any price on their marginal gas consumption. Tsygankova (2010) uses an elasticity of -0.4, as market reforms are expected to bring on more price responsiveness in the Russian gas market.

been increased, as Russian authorities have signalled that prices to a larger degree should reflect market prices in Europe. However, full netback pricing (i.e., prices equal to European prices minus transport costs to Europe) seems less likely than before, given the significant price increases in the European market over the last five years. Moreover, from a Russian welfare perspective, netback pricing is not optimal given that Russia exploits its market power in the European market. The optimal policy is rather to set prices equal to the full marginal costs of production, including the shadow costs of the resource. Hence, in our model we assume that Russia will follow such a price policy in the long run. This is fairly consistent with actual gas prices in Russia in the baseyear 2009. We then have the following first order condition for the Russian gas market:

$$c_{Rt}(A_{Rt}) + \lambda_{Rt} = p_t^R \tag{12}$$

Equations (8) and (11) must then be extended for the Russian producer to account for both exports and supply to the domestic market.

So far we have described what we refer to as the Benchmark scenario. Next, we assume that in the Shale gas scenario, large volumes of extra gas are supplied into the European market. This could be a mixture of U.S. LNG exports, other LNG volumes that are rerouted from the U.S. to the European market, and European shale gas (e.g., in Poland). We treat these extra volumes, which gradually come into the market after 2020 and reach a plateau of 150 bcm in 2035, as exogenous.[11]

Since the model does not distinguish between investments and production decisions, nor account for costs of adjustments, the model will tend to overestimate the initial effects of a shift in expectations. However, we are mostly interested in the *direction* of change in initial supply, and not so much in the size.

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[11] Although there is no doubt that there has been a major shift in expectations regarding future production of unconventional gas, there is no consensus about the size of this shift nor its impact on the European gas market. To put our numbers into perspective, however, in 2007 EIA expected that the U.S. would import around 150 bcm in 2030. Five years later, EIA expects an *export* level in 2035 of 70 bcm (EIA, 2007, 2012). Moreover, EIA (2011) expects European unconventional gas production to increase from practically nothing in 2015 to around 70 bcm in 2035. IEA (2012) is less optimistic about European unconventional gas production, but projects global unconventional gas supply to increase by 800 bcm in the period 2010-2035 (New Policies Scenario).

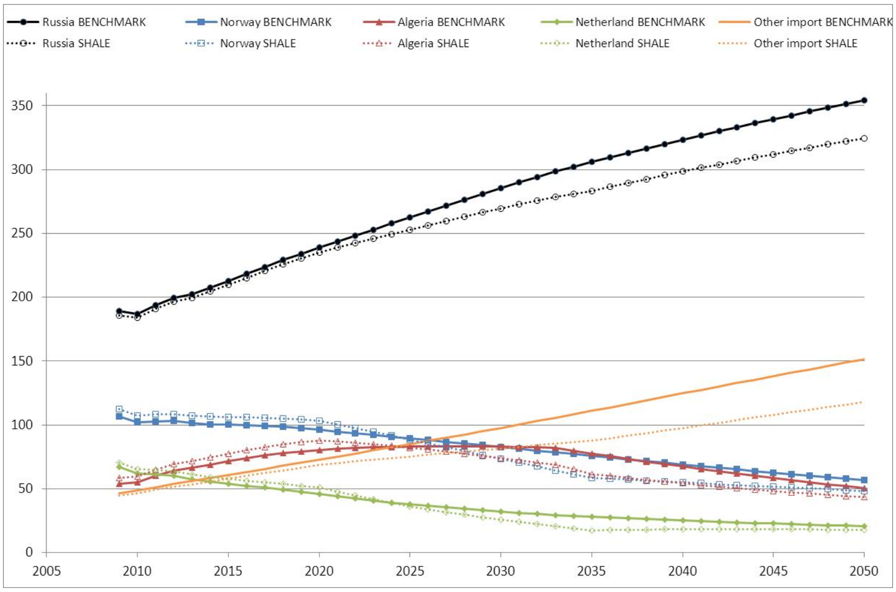

Figure 1: Supply of gas to the European market in Benchmark and Shale_gas scenarios. Bcm per year

4 Simulation results

4.1 Benchmark scenario

We now turn to the simulation results, where we are interested in the effects of a shift in expectations regarding future supply to the European gas market, that is, the difference between the scenarios shale gas and Benchmark. First, however, let us consider the Benchmark scenario, and check that it fits reasonably well with actual and projected supply (and demand). Figure 1 displays how supply from different producers develop until 2050. We see that Russian exports to Europe almost double during this period, increasing Russia's market share from 32% in 2009 to 54% in 2050. Exports from Norway and the Netherlands are reduced by respectively one third and two thirds, while Algerian exports first increase and then decrease to a level one quarter above baseyear levels.[12] LNG and other imports besides Russia/Algeria triple over this period, while other

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[12] In calibrating the model, we added a temporary cost element for Algeria, which declines to zero after 25 years. This cost element reflects political and other unquantified costs that may explain why Algeria, with total unit costs comparable with Norway but more reserves, produce only two thirds of Norwegian output.

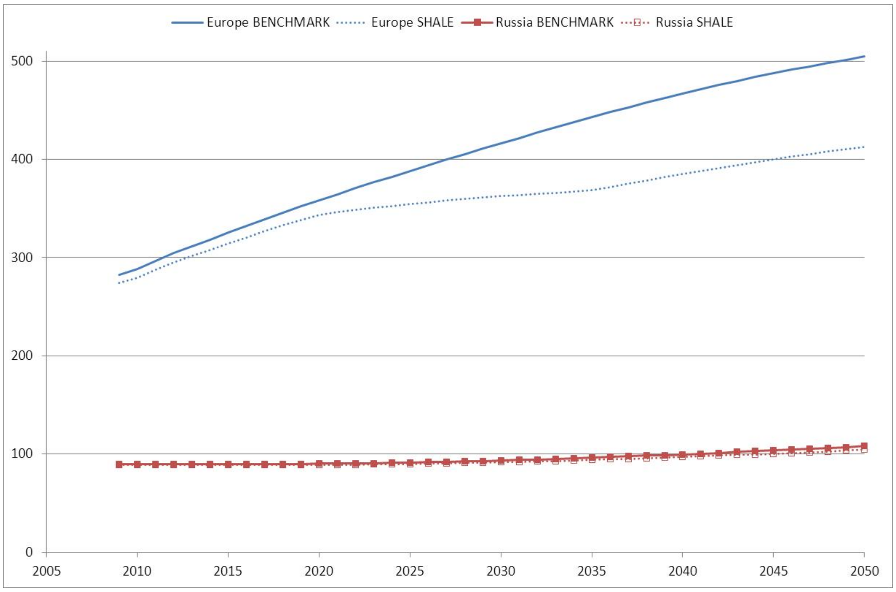

Figure 2: Price of gas in the European market in Benchmark and Shale_gas scenarios. $ per toe

domestic production in Europe declines substantially (by assumption). Total gas consumption increases by around 10% until 2050. This is less than what the IEA (2012) and others now project, but remember that the Benchmark scenario by construction has an outdated view on future supply of unconventional gas (because shale gas is not included).[13] Without shale gas in the benchmark model, the gas prices will higher and as a result, the gas consumption lower than in IEA's projections. The direction of changes in market shares observed in the figure are in line with most expectations about the European gas market, whether or not unconventional gas supply is accounted for.

The gas price in Europe increases from 280 to 500 $ in real prices per toe during the period 2009-2050 (see Figure 2), reflecting diminishing levels of profitable gas resources in most countries. The exceptions are Russia, which still holds large volumes of not too costly gas in 2050, and imports from other regions (e.g., LNG). As a consequence, Russian domestic prices stay around 100 $ per toe during the whole time horizon (Russian gas demand increases by two thirds during this time period).

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[13] In the Shale_gas scenario, European gas demand increases by around 20% during the same period.

4.2 Increased supply of unconventional gas

We next consider the effects of adding substantial volumes of unconventional gas into the European market, gradually increasing from zero in 2020 to 150 bcm from 2035 onwards. From Figure 2 we see that the gas price increases much more slowly in the shale gas scenario than in the Benchmark scenario, and is 50-90 $ per toe below the Benchmark price during the last 20 years of our time horizon. We further notice that the gas price drops in the shale gas scenarios even before the extra volumes of unconventional gas enter the market.

The explanation for the immediate price effect is that the future price decrease gives non-renewable resource owners incentives to move some of its production forward in time, cf. the theoretical discussion above. As seen in Figure 1, all gas producers reduce their supply from around 2025 in the shale gas scenario (compared to the Benchmark scenario). Moreover, Norway, Algeria and the Netherlands all produce more in the shale gas scenario than in the Benchmark scenario in the first 15 years. Hence we obtain the immediate price drop.

The results so far are as expected, given the findings in previous literature (e.g., the Green paradox literature referred to in Section 1). However, we notice from Figure 1 that Russian gas exports to Europe do not increase initially - it declines persistently throughout our time horizon in the shale gas scenario vis-a-vis the Benchmark scenario. Thus, Russia acts quite differently from the other Cournot players.

The reason is that Russia has vast amounts of gas reserves. Hence, its behaviour is more driven by the current market situation than by future market expectations. This is seen in Figure 3, which shows how unit production costs, the shadow price of the resource, and the oligopoly rent for Russia develop over time in the two scenarios. As the figure shows, the shadow price is in the range 10-20 $ per toe, whereas the oligopoly rent increases from 150 $ per toe initially to 350 $ per toe in 2050 in the Benchmark scenario. Thus, the non-renewability issue is not particularly pressing for Russia. When the other Cournot players produce more initially in the shale gas scenario, it is optimal for Russia to cut back on its supply to Europe.

These results are consistent with the findings in Section 2, where we considered a large player with sufficiently large resources. Here we have seen that Russia has so much more gas resources than other players in the European market that an increase in future supply to this market will reduce Russian supply both today and in after the entry of shale gas.

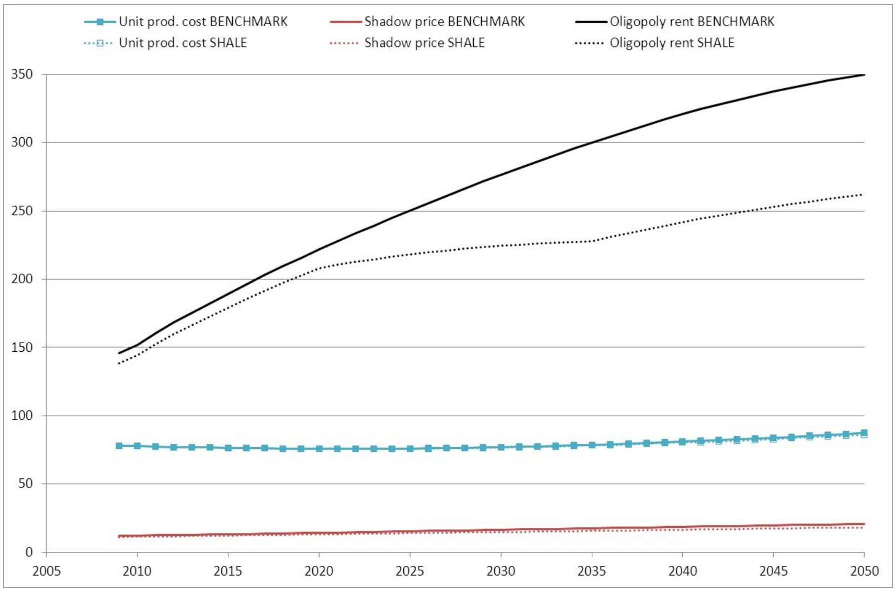

Figure 3: Unit production costs, shadow price and oligopoly rent for Russia. $ per toe

In the Appendix we show the development of costs and rents for the three other Cournot players. We see that the shadow prices of their gas resources are significantly greater than the oligopoly rents for all these three players, i.e., quite the contrary of what we see for Russia in Figure 3.

As a conseqence of lower gas prices and reduced market share for Russia throughout our modeling horizon, Russian discounted profits over the period 2009-2050 decline by 15%. Russia is the biggest Cournot producer and has the largest willingness to reduce production after entrance of the shale gas in order to prevent a price drop. Russia therefore suffers a relatively large loss of profits. The other Cournot players also lose profits, but somewhat less (10-11%).

The qualitative results, i.e., that Russia cuts back on its supply while the other Cournot players produce more initially, is robust to various assumptions about when, how quickly and how extensively unconventional gas supply enters the European gas market.

How much smaller must Russian reserves have been before Russia, too, would have increased initial exports? Simulations suggest that remaining reserves must have been more than 60 percent lower for this to happen. Thus, the results are also robust with respect to Russia's remaining reserve level.[14]

4.3 Other potential reductions in future residual demand

So far we have focused on additional supply of unconventional gas. However, the future residual demand for gas could be altered in other ways, too. How would that affect initial supply from the Cournot producers? Would we get the same qualitative results? To test this, we have simulated the effects of i) a downward shift in the inverse supply function of LNG/pipeline imports, ii) a downward shift in gas demand, and iii) introduction of a unit tax on gas consumption.

With increased imports through LNG and pipelines (i.e., besides Russian/Algerian and unconventional gas), implemented through a more rapid fall in the inverse supply function of such imports after 2025, we get quite similar results as with more unconventional gas. That is, Russian exports to Europe decline initially, while exports from Norway, the Netherlands and Algeria increase. Note that the construction of this scenario differs qualitatively from the shale gas scenario - in the latter scenario we make an exogenous quantity shift while in the former scenario we make the import supply function more price-responsive.

A downward shift in the demand function after 2025 also leads to the same qualitative results with respect to initial supply from the four Cournot players.

On the other hand, introducing a unit tax on gas consumption from 2025 leads to *increased* initial supply from Russia as well as from the other Cournot producers. The reason is that the consumption tax shifts down the inverse demand function facing the producers, implying that the producers face a less elastic demand. As a result, it is more profitable for large producers to curb production in order to raise the price they receive. Thus, being the biggest producer (especially after 2025), Russia cuts back its supply to Europe relatively more than the other Cournot players. Hence, Russia's incentives to save resources before 2025 are reduced more than in the other scenarios with reduced future residual demand. At the same time, the other Cournot players' incentives to accelerate extraction is dampened compared to the other scenarios (since Russia to a larger degree cuts back on its future supply). Altogether, all Cournot producers find it profitable to slightly increase their initial supply.

In terms of the theoretical model, Russia, being the largely dominant producer, reduces future supply substantially in order to exploit the enhanced

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[14] It is not straightforward to relate the reserve levels of the four Cournot players to the analytical model in Section 2, as Russia also supplies its domestic market in the numerical model.

market power granted by the decline in demand elasticity. This strengthens the intertemporal effect on Russia to accelerate production, because it reduces Russia's incentive to save resources for the future. Moreover, it weakens the interemporal effect on the other countries. The reason is that the decline in future Russian supply ameliorates the effect of future taxation. The associated low acceleration of supply from non-Russia then decreases the static effect on Russia to reduce current production. This explains why a tax policy that decreases both future demand and future demand elasticity may induce Russia to increase early supply, whereas incidents that primarily reduce future demand induce Russia to cut back early supply.

The last example illustrates that Russia does not have endless resources after all. It is optimal for this producer, too, to consider future as well as current market conditions. In addition to supplying European gas consumers, Russia has to supply its domestic market as well, which consumes a large share of Russian gas production. Thus, the impacts on initial market shares of changes in future market conditions depend not only on whether residual demand increases or decreases, but also on *how* it is changed.

5 Conclusions

In a non-renewable resource market, supply is governed both by current prices and the resource rent. As is well known, new information about bleaker future market conditions reduces the resource rent and thereby accelerates supply.

In this paper, we have investigated how changed expectations about future market conditions affect current supply in a non-renewable market characterized by Cournot competition in strategic substitutes. We find that market power induces firms to cut back some of the increase in aggregate short-run production induced by bleaker future prospects, as compared to a resource market with competitive firms. Indeed, a firm that endows a sufficiently large share of the resource may reduce current production if the net present value of the resource declines in the future. The reason is that players with extensive resources care less about scarcity issues and the resource rent, whereas current market considerations is important. Therefore, as players with less resources accelerate their supply, it may be optimal for a large player to cut back on its supply in order to counteract the associated fall in the resource price.

Our results demonstrate that the production profile of heterogeneous firms' may be differently affected by changes in future demand under oligopoly. This is particularly relevant if the government cares about the composition of supply, e.g. because of energy security reasons. In this respect, it is interesting that our numerical simulation suggests that bleaker prospects for oligopolistic exporters of conventional gas to Europe, caused by the shale gas revolution in the US, will induce Russia to reduce short run exports of gas to Europe, whereas all other producers increase current production. The explanation is that natural gas is hardly a scarce resource in Russia and, consequently, there is little need for Russia to curb its current extraction in order to save more resources for the future. Hence, they act almost like a static Cournot player. That is, when other gas producers increase their supply, Russia cuts back.

Our results also suggest that market power may alleviate the so-called green paradox, because the acceleration of production and emissions caused by lower future demand is dampened. Importantly, however, aggregate production unambiguously increases in the short run also under Cournot competition. The green paradox is therefore not completely removed.

In order to derive theoretical results, the analytical model featured quite strict assumptions about functional forms. It is arguably reasonable, however, to expect that the mechanisms detected will be present in more general cases. In this respect, we observe that the theoretical results are supported by the more sophisticated numerical model.

6 Appendix

Here we present 3 figures from the numerical simulation.

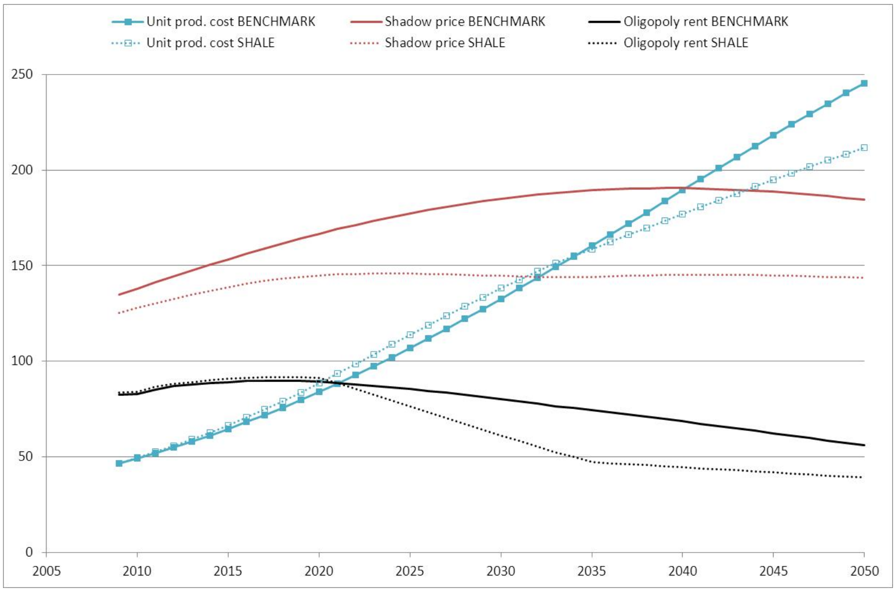

Figure 4: Unit production costs, shadow price and oligopoly rent for Norway. $ per toe

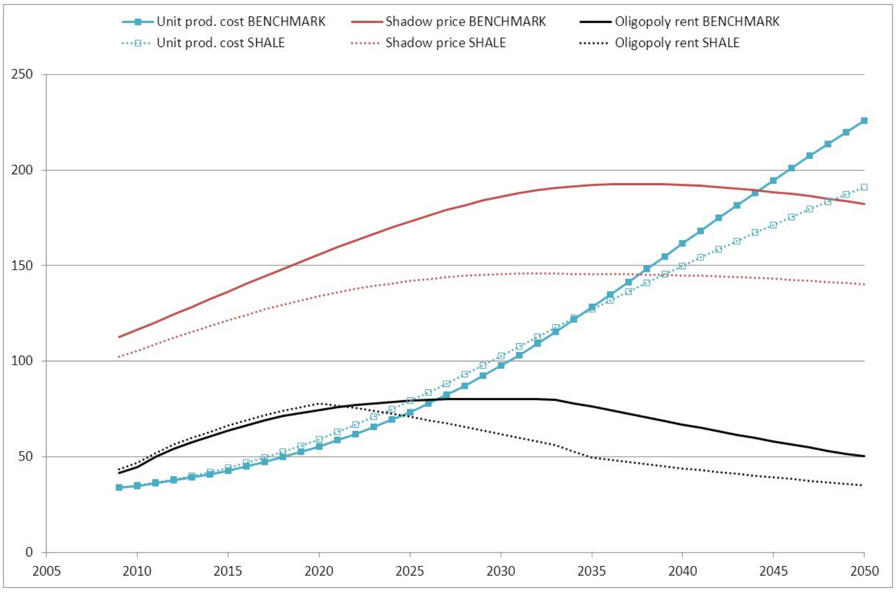

Figure 5: Unit production costs, shadow price and oligopoly rent for Algeria. $ per toe

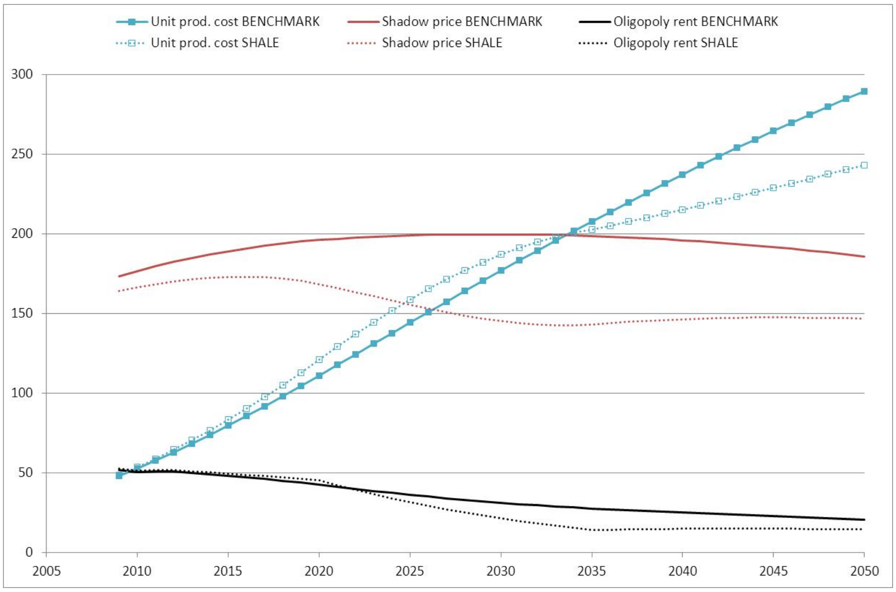

Figure 6: Unit production costs, shadow price and oligopoly rent for the Netherlands. $ per toe

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