Market power in the market for greenhouse gas emission permits - the interplay with the fossil fuel markets

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Abstract

Implementation of the Kyoto Protocol is likely to leave Russia and other Eastern European countries with market power in the market for emission permits. Ceteris paribus, this will raise the permit price above the competitive permit price. However, Russia is also a large exporter of fossil fuels. A high price on emission permits may lower the producer price on fossil fuels. Thus, if Russia coordinates its permit market and fossil fuel market policies, market power will not necessarily lead to a higher permit price.

Fossil fuel producers may also exert market power in the permit market, provided they conceive the permit price to be influenced by their production volumes. If higher volumes drive up the permit price, Russian fuel producers may become more aggressive relative to their competitors in the fuel markets if the sale of fuels is coordinated with the sale of permits. The result is reversed if high fuel production drives the permit price down.

Keywords: Climate policy, gas, market power, emission permits.

JEL codes: L13, Q28, Q48.

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1 Introduction

The Kyoto Protocol requires that the average annual emissions of a basket of six greenhouse gases in the industrialized countries do not exceed 95 per cent of 1990 emissions in the period 2008-2012. The United States have withdrawn from the agreement. Nevertheless, it is likely that a sufficient number of countries will ratify the agreement, so that it may enter into force.[1] This paper takes as its starting point that the Kyoto Protocol (or a similar climate agreement) will be implemented.

Parties of the Kyoto Protocol are allowed to engage in international emission trading. Some countries may become large traders and thus be in a position to exercise market power in the permit market. As pointed out by Hahn (1984), the degree of market power in the permit market depends on the initial allocation of permits. The literature on the economic impact of the Kyoto Protocol suggests that Russia and other Eastern European countries will become large exporters of permits (see Weyant and Hill (1999) and Weyant (1999)). Although the US withdrawal from the agreement will reduce the demand for permits, Russia and other Eastern European countries will still have a large share of the permit supply as their initial allocation of permits is expected to exceed their business as usual emissions. It is therefore quite likely that these countries will be able to exercise some monopoly power in the market for emission permits. A recent quantitative analysis by Böhringer (2002) concludes that the region "Former Soviet Union" can significantly increase its benefit of the agreement by restricting its supply of permits.

Utilizing the market power in the permit market will increase the permit price. A high price on emission permits, however, may reduce the demand for fossil fuels. Hence, it is not obvious that a fossil fuel exporting country will benefit from utilizing its market power in the permit market. In this paper, we explore the conditions under which it is profitable for a permit exporting country to utilize its market power to drive up the permit price and when it is profitable to keep the permit price low.

The presence of market power on the producer side of the fossil fuel markets adds an extra dimension to our analysis, because the fuel producers may be able to utilize their market power to influence the price of emission permits. In other words, oligopolistic fuel producers may have market power in the permit market as well. This requires, of course, that the combustion of fuels in the relevant fuel markets constitutes a significant part of the to-

[1] The agreement will not enter into force, until it has been ratified by at least 55 countries which together contribute to at least 55 percent of the industrialized world's greenhouse gas emissions in 1990.

tal emissions by the countries participating in permit trade. A country like Russia, which is a large oil and gas producer, may therefore be able to influence the price of emission permits not only directly through the supply of permits, but also indirectly through its role as a large oil and gas producer. Russia enjoys a market share of 42% in the European gas market and 10% in the global oil market (IEA (2001a), IEA (2001b)). Moreover, based on projections by the International Energy Agency, we have calculated that the combustion of gas in the European gas market will cause around 20% of total greenhouse gas emissions in all industrialised countries in 2010, excluding the USA. The corresponding figure for the global oil market is 33% (IEA, 2000). Hence, it is not unlikely that Russian gas and oil producers may be able to exercise some market power in the permit market.

This paper explores the consequences for the permit and fossil fuel markets of market power in the permit market, taking into account the fact that market power in the permit market can be exercised both directly through the supply of permits and indirectly through the supply of fossil fuels. Furthermore, we show how the potential coordination of supply decisions for fossil fuels and emission permits might influence the equilibrium both in the permit market and in the fossil fuel markets. Finally, we discuss the desirability of coordinating the supply of emission permits and the supply of fossil fuels.

The interaction of permit markets with product markets with imperfect competition has been analyzed in several studies. Misiolek and Elder (1989) analyze a product market with a dominant firm facing a fringe of price takers and show that the dominant firm may buy permits in order to raise the cost of rivals in the same industry or to block entry of new competitors. In a similar vein, von der Fehr (1993) shows that emission permits can be used strategically by oligopolistic firms for predatory and exclusionary purposes. Borenstein (1988), Malueg (1990) and Sartzetakis (1997) consider the welfare effect of a competitive permit market in the presence of imperfect product markets, showing that although a competitive permit market will ensure cost efficient abatement efforts, it may lead to inefficiencies in production decisions when the output market is oligopolisitc.

In previous studies, emissions are assumed to arise in the production process. In our analysis, emissions are caused by the combustion of fossil fuels, i.e., on the consumer side. Thus, there is no need for the fuel producers to hold emission permits. This implies that the permit market cannot be used by the fuel producers to gain any strategic advantages in the fuel market. Of course, as already discussed, the fuel producers might be able to influence the price of permits and thus the equilibrium of the fuel market through their production decisions. But since all fuel producers will be symmetrically affected, such actions have no strategic effect.

Another novelty of our study is that we analyze the impact of coordinating the supply of permits with the supply in output markets in an environmnet where not only the permit market equilibrium affects the output market, but where also the output market equilibrium influences the price of emission permits. As pointed out by Moe and Tangen (2000), it is not unreasonable that the Russian authorities will allocate a substantial share of the country's emission permits to various commerical agents. They also argue that the dominating Russian gas producer, Gazprom, may be left in control of a large share of Russia's permits. In this case, the supply of permits may be coordinated with the supply of gas in order to maximize the total economic rent. We show that such coordination may have important implications for the equilibrium price of emission permits. We also demonstrate that coordination will have strategic effects in the non-competitive fuel markets. Finally, we show that although coordination implies that externalities between the sellers of emission permits and fuel producers are internalised, coordination might in some cases reduce rents, because coordination can lead to a strategic disadvantage in non-competitive fuel markets.

The next section presents the basic model. There are two markets; a permit market in which there is only one agent with market power and an output market where competition is modelled as a symmetric Cournot duopoly. This output market structure is intended to capture essential aspects of the European gas market, where Russia is the dominating actor, with Norway and Algeria as the two other major suppliers. Henceforth, we will therefore think of the output market as the gas market, although the basic reasoning probably would apply equally well to other non-competitive fuel markets, such as the oil market. The model takes into account that natural gas is sold in competition with other primary energy sources. Some of these, such as oil and coal, cause larger emissions of greenhouse gases per energy unit than does natural gas. Others, such as hydro and nuclear power, do not cause greenhouse gas emissions at all. We demonstrate that both the nature of the competition between natural gas and alternative fuels, as well as the pollution intensity of alternative fuels will be of crucial importance for the results.

Section 3 characterises a benchmark case with perfect competition in the permit market along with oligopolistic gas market behaviour. The consequences of market power in the permit market are then explored in Section 4 by letting one agent (Russia) be a monopoly supplier of emission permits, maximizing the rent from permit sale. The standard monopoly pricing rule applies. At the same time, profit maximizing gas producers are able to influence the permit price. The consequences for the gas market equilibrium are ambiguous, depending on the degree of substitution and on the relative emission intensities between gas and alternative energy sources. In Section 5, we examine the case of coordination of gas market and permit market policies. The standard monopoly pricing rule is then modified; it may even be optimal to sell permits below marginal abatement costs. Coordination will affect Russia's strategic position vis-à-vis its competitors in the gas market. Again, the degree of substitution and the relative emission intensities vis-à-vis alternative energy sources are crucial for the results.

Section 6 discusses whether or not it is profitable for Russia to coordinate the supply of permits and the supply of gas. Since coordination in some cases may weaken Russia's strategic position in the gas market, it is not obvious that coordination is profitable. Section 7 concludes.

2 The basic model

We model the European gas market as a symmetric Cournot duopoly. Two producers, R (Russia) and N (Norway and Algeria), export their entire production[2] to a group of countries E (the European Union), which in our model do not exercise any market power.[3] Production quantities are denoted x_g^R and x_g^N, respectively. Marginal costs of gas production are normalized to zero.

Natural gas is sold in competition with other primary energy sources. The inverse gas demand function is given by

$$p_g = p_g(x_g, x_a), \tag{1}$$

where x_g is gas consumption and x_a is the consumption of alternative fuels, and with the assumed properties $\partial p_g/\partial x_g < 0$ and $\partial p_g/\partial x_a \leq 0$.

The inverse demand function of the alternative fuel is

$$p_a = p_a(x_a, x_g), \tag{2}$$

with $\partial p_a/\partial x_a < 0$ and $\partial p_a/\partial x_g \leq 0$.

[2] In practice, a substantial share of Russian gas production is for the domestic market. To incorporate the domestic gas market in Russia would complicate the analysis. In particular, we would need to take into account the effect of changing gas prices on consumer welfare in Russia. But since the domestic gas market in Russia is not well integrated with the rest of the European gas market, it is not clear how this analysis should be appropriately conducted. We therefore ignore this aspect.

[3] Historically, the imports of gas to the European Union has been managed by a few large gas companies. The implementation of the gas market directive of the Euroepan Commission will however imply a more competitive gas market structure.

The consumption of one unit of gas causes e_g units of greenhouse gas emissions, while the emission factor of the alternative fuel is e_a. Some of the substitutes for natural gas, such as oil and coal, cause larger emissions of greenhouse gases per energy unit than does natural gas. Others, such as hydro and nuclear power, do not cause greenhouse gas emissions at all. Therefore e_a will be allowed to take on values both larger and smaller than e_g.

An international environmental agreement à la the Kyoto Protocol defines upper bounds on the emissions of greenhouse gases in each of the participating countries. We assume that emission permits are traded internationally at the permit price q. A positive price of permits implies a downward shift in the inverse demand function of fuels. Producers are then faced with the following effective inverse demand functions

$$p_i(x_i, x_j) - e_i q, \ i, j = a, g, \ i \neq j. \tag{3}$$

The market for the alternative fuel is assumed to be perfectly competitive. The equilibrium quantity is then found where the "producer price" given by (3) equals the marginal costs of production. We characterise the equilibrium in the market for the alternative fuel in a reduced form as follows

$$x_a = x_a(x_g, q). \tag{4}$$

The equilibrium quantity of the alternative fuel x_a will decline with the gas volume x_g because the fuels are substitutes ($\partial x_a / \partial x_g \leq 0$). A higher permit price will also reduce the quantity of the alternative fuel (for a given level of x_g) as long as the emission factor e_a is positive ($\partial x_a / \partial q \leq 0$).

In the gas market, the equilibrium condition is given by

$$x_g^R + x_g^N = x_g. \tag{5}$$

The profit of the gas producer in country c, π_g^c, can now be defined as a function of the gas production quantities and the price of emission permits

$$\begin{aligned} \pi_g^c(x_g^R, x_g^N, q) &= (p_g(x_g, x_a) - e_g q)\, x_g^c \\ &= \left(p_g(x_g^R + x_g^N, x_a(x_g^R + x_g^N, q)) - e_g q\right) x_g^c, \quad c = R, N. \end{aligned} \tag{6}$$

Profit maximising behaviour will determine the equilibrium gas quantities as a function of the permit price ($x_g^c = x_g^c(q)$, $c = R, N$).

The price of emission permits q is determined by supply and demand in the permit market. We assume that there is only one country (Russia) that can influence the permit price directly through permit trade. The demand for emission permits faced by the Russian permit exporter can be divided into two components. First, there is permit demand generated by gas consumption and consumption of the alternative fuel (i.e., $e_a x_a + e_g x_g$). Second, there is the residual permit demand from all other emission sources in the participating countries, represented by the demand function $d(q)$. The residual permit demand is assumed to decline with the price of permits ($d_q < 0$). The net demand for emission permits faced by the Russian permit exporter is then $e_a x_a + e_g x_g + d(q) - Q$, where Q is the total emission quota allocated to the participating countries (except Russia).

Let y denote Russian export of emission permits. The Russian profit from permit exports, π_p^R, is then

$$\pi_p^R(y) = qy - c(y), \tag{7}$$

where $c(y)$ represents the costs of generating y units of permits for export. The shape of the cost function is determined by the initial emission quota allocated to Russia and by the domestic abatement costs. Due to a high initial allocation of quotas to Russia in the Kyoto Protocol, Russia may be able to export a certain amount of permits at zero costs. Higher export levels will require domestic abatement, though.

The equilibrium condition in the market for emission permits can now be defined as

$$e_a x_a \left(x_g^R + x_g^N, q\right) + e_g(x_g^R + x_g^N) + d(q) - Q = y. \tag{8}$$

Eq. (8) defines the equilibrium permit price as a function of the total gas consumption and the Russian supply of emission permits, $q = q(x_g^R + x_g^N, y)$.

Without coordination of gas and permit market policies in Russia, the optimal Russian supply of emission permits is found by maximisation of π_p^R with respect to y, (see Eq. (7)) and the optimal Russian gas sales are found by maximisation of π_g^R with respect to x_g^R (see Eq. (6)) Coordination implies that both the gas seller and the permit seller in Russia take into account the impacts on each others' profits. In effect, this implies that both agents maximise the total profit for Russia, π^R, given as

$$\pi^R = \pi_p^R + \pi_g^R. \tag{9}$$

Four variants of the model will be analyzed. In Section 3, we assume that the permit market is competitive. Both gas sellers and permit sellers then take the price of permits q as given. Sections 4 and 5 investigate the impact of market power in the market for emission permits. Both gas sellers and permit sellers are then assumed to be able to influence the permit price. The non-coordination case is discussed in Section 4, whereas coordination is analyzed in Section 5.

Before we proceed, it will be useful to derive a few comparative static results. Consider how the equilibrium permit price is affected by changes in the level of permit exports from Russia (y) and the level of gas production and consumption (x_g^c) in our model. Assuming a stable equilibrium, we have

$$\frac{\partial q}{\partial y} = \frac{1}{e_a \frac{\partial x_a}{\partial q} + d_q} < 0, \tag{10}$$

$$\frac{\partial q}{\partial x_g^c} = -\frac{e_a \frac{\partial x_a}{\partial x_g^i} + e_g}{e_a \frac{\partial x_a}{\partial q} + d_q} \gtreqless 0. \tag{11}$$

We notice that while an increase in the supply of emission permits has a negative impact on the permit price, the impact of higher gas production is ambiguous. In particular, if the alternative fuel is more polluting than natural gas ($e_a > e_g$) and at the same time is a close substitute for gas ($\partial x_a / \partial x_g^i$ close to -1), higher gas production may cause a fall in the permit price. Of course, the first order effect of increased gas production and consumption is a higher permit price, because the demand for permits increases. However, when natural gas has a substitute which causes greenhouse gas emissions, the direct effect on emissions of increasing the gas sales (and thus reducing the gas price) will be counteracted by substitution away from the alternative fuel. If the alternative fuel is less polluting than natural gas, this substitution effect cannot outweigh the first order effect on emission demand, and the permit price is then bound to increase. If the fuels are perfect substitutes ($\partial x_a / \partial x_g^i$ equal to minus one), total emissions will increase (decrease) as long as natural gas is more (less) polluting than the alternative fuel. With less than perfect substitutability, the alternative fuel must be significantly more polluting than natural gas in order for total emissions and the permit price to decline.

In order to put the analysis in perspective, let us compare the emission factor of natural gas with some of its close substitutes. Coal, which is the most polluting alternative to natural gas, has an emission factor of some 3.9 tonne carbon dioxide per tonne oil equivalent. The emission factor of natural gas is about 2.34. Hence, if natural gas substitutes with coal only, the reduction in coal consumption (measured in energy units) must be 0.6 or larger per unit of increased gas consumption in order to make the permit price decline (i.e., $\partial x_a / \partial x_g < -0.6$). In the case of substitution with oil only, the degree of substitutability would have to be higher; the factor would then increase to around 0.77.

3 Perfect competition in the permit market

In order to establish a reference point, we solve the model for the case with perfect competition in the permit market. Formally, this implies that all agents take the permit price q as given. Assuming no coordination of gas market and permit market policies in Russia, the first order conditions are

$$\frac{\partial \pi_p^R}{\partial y} = q - c' = 0, \tag{12}$$

$$\frac{\partial \pi_g^R}{\partial x_g^R} = p_g - e_g q + \left(\frac{\partial p_g}{\partial x_g} + \frac{\partial p_g}{\partial x_a} \frac{\partial x_a}{\partial x_g^R} \right) x_g^R = 0, \tag{13}$$

$$\frac{\partial \pi^N}{\partial x_g^N} = p_g - e_g q + \left(\frac{\partial p_g}{\partial x_g} + \frac{\partial p_g}{\partial x_a} \frac{\partial x_a}{\partial x_g^N} \right) x_g^N = 0. \tag{14}$$

The interpretations are straightforward: Eq. (12) states that with perfect competition in the permit market, the permit price equals marginal abatement costs, and Eqs. (13) and (14) are simply the standard Cournot conditions, including the cross-price effect through substitution with the alternative energy market.

We immediately realise that coordination of gas and permit market policies in Russia will have no impact on the equilibrium. As long as the permit price is taken as given, the level of permit exports will have no impact on the profits in the gas market, and gas market exports will have no impact on the profit from permit sale.

Proposition 1 *Coordination of gas and permit trade does not influence the equilibrium if there is perfect competition in the permit market.*

Proof. As long as q is regarded independent of y and x^R, the payoffs from gas export and quota export are independent, implying that $\partial \pi^R / \partial y = \partial \pi_p^R / \partial y$ and $\partial \pi^R / \partial x_g^R = \partial \pi_g^R / \partial x_g^R$. Hence, the first order conditions are identical in the two cases. ■

4 Uncoordinated market power in the permit market

Consider now the case where both the permit seller and gas sellers have market power in the market for emission permits in the sense that they are able to influence the price of emission permits. Of course, the fact that the permit exporter has market power in the permits market does not necessarily imply that the gas sellers also have such market power. Even if the gas sellers have market power in the gas market, the share of gas in total emissions may be so low that they do not conceive of any market power in the permit market. The opposite may also be the case; all agents in the permit market may be too small to exert market power at the same time as there are a few big producers of fossil fuels that exert substantial market power both in the market for fossil fuels and in the market for permits.

Assuming that there is no coordination of gas and permit market policies, the first order conditions are now

$$\frac{\partial \pi_p^R}{\partial y} = q - c' + \frac{\partial q}{\partial y} y = 0, \tag{15}$$

$$\frac{\partial \pi_g^R}{\partial x_g^R} = p_g - e_g q + \left(\frac{\partial p_g}{\partial x_g} + \frac{\partial p_g}{\partial x_a} \frac{\partial x_a}{\partial x_g^R} \right) x_g^R + \frac{\partial q}{\partial x_g^R} \left(-e_g + \frac{\partial p_g}{\partial x_a} \frac{\partial x_a}{\partial q} \right) x_g^R = 0, \tag{16}$$

$$\frac{\partial \pi^N}{\partial x_g^N} = p_g - e_g q + \left(\frac{\partial p_g}{\partial x_g} + \frac{\partial p_g}{\partial x_a} \frac{\partial x_a}{\partial x_g^N} \right) x_g^N + \frac{\partial q}{\partial x_g^N} \left(-e_g + \frac{\partial p_g}{\partial x_a} \frac{\partial x_a}{\partial q} \right) x_g^N = 0. \tag{17}$$

Consider first the effect of market power on Russia's export of emission permits. Not surprisingly, Eq.(15) shows that the optimal permit export now is given by the standard formula for a monopolist's supply. For a given level of gas sales (x_g^R and x_g^N), the level of permit export is reduced in order to raise the permit price and extract monopoly rents.

The effect on the gas market equilibrium is more ambiguous. The presence of market power in the permit market is captured by the last term on the left hand side of Eqs. (16) and (17). The expression within the brackets, $\left(-e_g + \frac{\partial p_g}{\partial x_a} \frac{\partial x_a}{\partial q} \right)$, represents the effect of increased price of emission permits on the producer price of gas. The term $-e_g$ reflects the direct, negative impact of a higher permit price on the producer price of gas. The other term, $\frac{\partial p_g}{\partial x_a} \frac{\partial x_a}{\partial q}$, is an indirect, positive effect on the producer price of gas via substitution towards gas as the price of permits increases for the alternative fuel. It turns out that the net effect of these terms is ambiguous. Statement (18) summarises the condition for a declining producer price of gas when the permit price increases

$$\frac{\partial (p_g - e_g q)}{\partial q} = -e_g + \frac{\partial p_g}{\partial x_a} \frac{\partial x_a}{\partial q} < 0 \Longleftrightarrow \frac{e_g}{e_a} > \frac{\partial p_g / \partial x_a}{\partial p_a / \partial x_a - \tilde{c}''} \tag{18}$$

where $\tilde{c}(x_a)$ is the cost of producing the alternative fuel.[4] The producer price

[4]Equilibrium in the market for the alternative fuel is found where $p_a(x_a, x_g) - e_a q =$

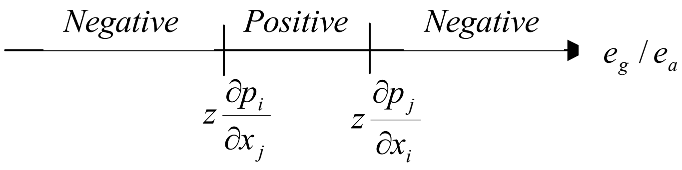

Figure 1: Effect of market power on marginal profitability of gas production

of gas may rise if e_a is high relative to e_g and the cross-price effect is strong, because a higher price of permits will then create a strong substitution effect towards gas, which is the cleaner fuel.

According to Eq. (11), the effect on the price of emission permits of changes in gas output is also ambiguous (i.e., $\partial q/\partial x_g^i \lesseqgtr 0$). It follows from Eq. (11) that $\partial q/\partial x_g^i > 0$ if and only if $e_a \frac{\partial x_a}{\partial x_g^i} + e_g > 0$. Statement (19) shows the condition for a rising permit price as gas volumes increase[5]

$$\frac{\partial q}{\partial x_g^c} > 0 \Longleftrightarrow \frac{e_g}{e_a} > \frac{\partial p_a/\partial x_g^c}{\partial p_a/\partial x_a - \tilde{c}''} \quad c = R, N. \tag{19}$$

A relatively high emission factor of the alternative fuel combined with a strong cross-price effect will imply that higher gas volumes cause a fall in the price of permits. Higher gas consumption will then go together with a strong fall in the consumption of the pollution-intensive alternative fuel, leading to a fall in the total demand for permits.

What is then the total effect of market power in the permit market on the behaviour of the gas producers? It turns out that the degree of ambiguity in the results may be reduced when we combine the expressions discussed above. Define $z \equiv 1/(\partial p_a/\partial x_a - \tilde{c}'')$. By combining the expressions in (18) and (19), we find that the sign of the market power term (i.e., the last term in Eqs. (16) and (17)), is determined as shown in Figure 1 (where i, j denote a, g and $i \neq j$).

Proposition 2 *For $e_g/e_a \notin [z\partial p_i/\partial x_j, z\partial p_j/\partial x_i]$, $i, j = a, g$, $i \neq j$, gas producers' market power in the market for emission permits will reduce the marginal profitability of gas production, inducing a fall in gas production levels. Otherwise, gas production will tend to increase.*

$\tilde{c}'(x_a)$. Implicit differentiation yields $\partial x_a/\partial q = e_a/(\partial p_a/\partial x_a - \tilde{c}'')$.

[5]Implicit differentiation of the equilibrium condition for the alternative fuel yields $\partial x_a/\partial x_g^c = -\partial p_a/\partial x_g^c/(\partial p_a/\partial x_a - \tilde{c}'')$.

Proof. We consider the effect of market power on x_g^R for a given level of x_g^N and y. It follows from (18) and (19) that the last term in Eq. (16), reflecting the existence of market power in the market for emission permits, is negative when $e_g/e_a \notin [z\partial p_i/\partial x_j, z\partial p_j/\partial x_i]$, $i, j = a, g$, $i \neq j$. The second order condition $(\partial^2 \pi_g^R/\partial (x_g^R)^2 < 0)$ implies that x_g^R must then decrease in order to satisfy Eq. (16). It is easily seen that the opposite result is obtained when $e_g/e_a \in [z\partial p_i/\partial x_j, z\partial p_j/\partial x_i]$, $i, j = a, g$, $i \neq j$. ■

The intuition is as follows: When e_g/e_a is sufficiently small, implying that gas substitutes with a relatively polluting energy source, increased gas production will tend to drive the permit price down, because the increase in gas consumption will replace the consumption of a more pollution-intensive fuel. A lower price on permits will create a strong positive shift in the demand for the alternative, pollution-intensive fuel and a corresponding negative shift in gas demand. The producer price of gas may then decrease, despite the fact that a reduction in the permit price has a direct positive impact on the gas producer price. In sum, an increase in gas production reduces the producer price of gas through adjustments in the permit price. Market power in the permit market thus makes gas production less profitable at the margin, calling for a reduction in the production level.

When e_g/e_a is sufficiently large, completely opposite effects are at work, but the end result is nevertheless the same. Increased gas sale drives up the price of emission permits, because gas is relatively pollution-intensive. A higher permit price will tend to reduce the producer price of gas, because the direct effect dominates the indirect one. The reason is that the higher price on permits only has a small impact on the price of the relatively clean alternative fuel and therefore induces only a moderate substitution effect towards gas.

Hence, both with high and low values of e_g/e_a, market power in the permit market tends to make gas production less profitable at the margin. For intermediary values, however, the opposite may be the result.

Proposition 3 *If $\partial p_a/\partial x_g = \partial p_g/\partial x_a$, gas producers' market power in the permit market will always induce reduced gas production.*

This result states that if the demand functions for gas and the alternative fuel are symmetric, market power in the permit market has an unambiguously negative impact on the marginal profitability of gas production. In this case, the relative pollution intensities are irrelevant for the conclusion.

5 Coordination of market power

We have seen that coordination of gas market and permit market policies makes no difference when the permit market is competitive. Turning to the case of a non-competitive permit market, this conclusion will have to be modified. When the agents are able to influence the price of permits, they will also be able to influence each others' profit. In effect, an externality will arise between the gas sellers and the permit seller. Since two of the agents in our model are located within the same country, the government might be interested in internalising the externality between the domestic agents in order to achieve higher revenues for the economy as a whole. This might for instance be achieved by organising the permit trade and the gas trade within one organisation.

In this section, we explore the consequences for the permit and gas markets of such coordination. The next section analyses whether or not coordination will be a profitable way of organizing these activities.

The profit functions in the case of coordination are given by (9) for the Russian agents and by (6) for the other gas producer. The first order conditions are:

$$\frac{\partial \pi^R}{\partial y} = q - c' + \frac{\partial q}{\partial y} y + \frac{\partial q}{\partial y}\left(-e_g x_g^R + \frac{\partial p_g}{\partial x_a}\frac{\partial x_a}{\partial q} x_g^R\right) = 0, \tag{20}$$

$$\frac{\partial \pi^R}{\partial x_g^R} = p_g - e_g q + \left(\frac{\partial p_g}{\partial x_g} + \frac{\partial p_g}{\partial x_a}\frac{\partial x_a}{\partial x_g^R}\right) x_g^R + \frac{\partial q}{\partial x_g^R}\left(-e_g x_g^R + \frac{\partial p_g}{\partial x_a}\frac{\partial x_a}{\partial q} x_g^R\right) + \frac{\partial q}{\partial x_g^R} y = 0, \tag{21}$$

$$\frac{\partial \pi^N}{\partial x_g^N} = p_g - e_g q + \left(\frac{\partial p_g}{\partial x_g} + \frac{\partial p_g}{\partial x_a}\frac{\partial x_a}{\partial x_g^N}\right) x_g^N + \frac{\partial q}{\partial x_g^N}\left(-e_g x_g^N + \frac{\partial p_g}{\partial x_a}\frac{\partial x_a}{\partial q} x_g^N\right) = 0. \tag{22}$$

By comparing Eqs. (20)-(22) with Eqs. (15)-(17), we realise that coordination now implies a different set of first order conditions for the Russian gas and permit exporters. The new term in Eq. (20) reflects the marginal effect of permit exports y on gas profits, while the new term in Eq. (21) refers to the marginal effect of gas exports on permit export revenues. However, neither of these additional terms has unambiguous implications for the marginal profitability of gas and permit exports.

Proposition 4 *Coordination of gas and permit market policies may increase or reduce the optimal markup on permits ($q - c'$). The optimal markup is reduced if $\frac{e_g}{e_a} > \frac{\partial p_g/\partial x_a}{\partial p_a/\partial x_a - \tilde{c}''}$ and increases otherwise. With coordination, the optimal markup on permits may be negative.*

Proof. It follows from (10) and (18) that the last term in Eq. (20) is positive if $\frac{e_g}{e_a} > \frac{\partial p_g/\partial x_a}{\partial p_a/\partial x_a - \tilde{c}''}$ and negative otherwise. In order to prove that the optimal markup may be negative ($q < c'$), assume that there is no substitution with alternative fuels ($\partial p_g/\partial x_a = 0$). Then, we see from (20) that $q < c'$ if $y - e_g x_g^R < 0$. It follows from the permit market equilibrium condition (8) that $e_g x_g^R$ ($+ e_g x_g^N$) can be increased by any amount without altering the equlibrium level of y, as long as this is met by a corresponding increase in Q. ■

If a lower price on permits increases the producer price of gas (cf. (18)), coordination will increase the marginal profitability of permit exports, because higher permit exports drive the permit price down and increase gas profits. Hence, for a given level of x_g^R and x_g^N, the export of permits will increase and the price of permits will be reduced relative to the non-coordination case. This happens when the alternative fuel is not too pollution-intensive and the degree of fuel substitution is weak. On the other hand, if the producer price of gas increases with the permit price, coordination will make it profitable to raise the markup over marginal abatement costs even further than in the non-coordination case. Coordination of gas and permit market policies thus has an ambiguous impact on the price of emission permits, depending on relative pollution intensities of alternative energy sources and on the degree of substitution.

With coordination of gas and permit market policies, it is no longer obvious that market power in the permit market implies a rise in the permit price relative to the case of a competitive permit market. By comparing Eqs. (12) and (20), we realise that for a given level of x_g^R and x_g^N, the price of permits may here be higher or lower than the competitive price, depending on the sign of the term $y - (e_g - \frac{\partial p_g}{\partial x_a}\frac{\partial x_a}{\partial q})x_g^R$. This term reflects the increase in total income from gas and permit exports following a marginal increase in the permit price. If gas export, measured in emission units ($e_g x_g^R$), is large relative to the permit export y, the optimal supply of permits may actually be higher, and the price of permits may be lower, than with a competitive permit market. If the cross-price effect with the alternative fuel is not too strong, a lower price on permits will then enhance gas incomes so strongly that it more than outweighs the positive effect of a high permit price on permit income.

Consider next the conditions for the optimal level of gas sales (Eqs. (21) and (22)). We realise that the first order conditions for the two gas producers are no longer symmetric. The coordination of gas market and permit market policies in Russia implies that the Russian gas producers will take into account the impact on the permit sellers' income. This is represented by the term $y\frac{\partial q}{\partial x^R}$ in Eq. (21).

Proposition 5 *Assume that $y > 0$. If increased supply of gas increases the price of permits ($\partial q/\partial x_g^c > 0$), coordination of permit market and gas market policies implies that the coordinating gas producer obtains a larger market share. If increased supply of gas reduces the price of permits ($\partial q/\partial x_g^c < 0$), the result is reversed.*

Proof. Assume that $x_g^R = x_g^N$. Eqs. (21) and (22) show that this is not an equilibrium unless $y = 0$. Define x_g^N so that Eq. (22) is satisfied. Then, if $y > 0$, the expression in Eq. (21) will be greater than zero as long as $x_g^R = x_g^N$ and $\frac{\partial q}{\partial x_g^R} > 0$. From the second order condition we have that $\partial^2\pi^R/\partial\left(x_g^R\right)^2 < 0$. Hence, an equilibrium requires that $x_g^R > x_g^N$. It follows straightforwardly that the converse is true when $\frac{\partial q}{\partial x_g^R} < 0$. ■

Ceteres paribus, a net exporter of emission permits benefits from higher permit prices. If increased supply of gas leads to a higher permit price ($\partial q/\partial x_g^c > 0$), coordination of gas and permit market policies will therefore increase the marginal profitability of gas exports. In effect, Russia becomes a more aggressive competitor in the gas market, increasing its market share. In this case, coordination creates a strategic advantage for the Russian gas exporter.

If, on the other hand, increased gas supply causes a fall in the permit price ($\partial q/\partial x_g^c < 0$), the coordination of permit and gas market policies in Russia will make Russia a less aggressive competitor in the gas market, and its market share will fall. Coordination thus creates a strategic disadvantage.

Some further insight into the optimal strategies in the case of coordination can be obtained by solving Eqs. (20)-(21). By utilising Eqs. (10) and (11), we obtain

$$\frac{-1}{e_a\frac{\partial x_a}{\partial x_g^c} + e_g}(p_g - e_g q + \frac{dp_g}{dx_g^R}x_g^R) = q - c', \tag{23}$$

$$p_g - e_g c' + \frac{dp_g}{dx_g^R}x_g^R - e_a\frac{\partial x_a}{\partial x_g^c}\frac{\partial q}{\partial y}\Phi = 0, \tag{24}$$

where $\frac{dp_g}{dx_g^R} \equiv \frac{\partial p_g}{\partial x_g} + \frac{\partial p_g}{\partial x_a}\frac{\partial x_a}{\partial x_g^R}$ and $\Phi \equiv y - (e_g - \frac{\partial p_g}{\partial x_a}\frac{\partial x_a}{\partial q})x_g^R$. The interpretation of Eq. (23) is that on the margin, the costs of exercising market power in the permit market from the demand side (i.e., via x_g^R) should equal the costs of exercising market power from the supply side (i.e., via y). To affect the permit price through reduced y has a cost of $q - c'$ per unit (i.e., the margin in the permit market). On the demand side, x_g^R must increase by

$1/(e_a \frac{\partial x_a}{\partial x_g^c} + e_g)$ units in order to increase permit demand by one unit, and the unit cost of increased x_g^R is reflected by the marginal profit in the gas market $-(p_g - e_g q + \frac{dp_g}{dx_g^R} x_g^R)$.

Eq. (24) has an interesting interpretation. Consider the case with no substitution between gas and alternative fuels (i.e., $\frac{\partial x_a}{\partial x_g^c} = 0$). Then Eq. (24) says that a profit maximising, coordinating gas producer should completely ignore the impact of gas supply on the permit price, provided the gas producer is subsidized so that the producer price of gas reflects the real social costs of permits c' rather than the monopoly price q.[6] In effect, the gas seller should then behave as if the permit market were competitive (taking the level of y as given). Things become somewhat more complicated when gas substitutes with another polluting energy source, though. Then, the gas supplier must also take into consideration the effect of changes in gas supply on total gas and permit profits via changes in the equilibrium consumption of the alternative fuel.

6 Is coordination profitable?

The positive analysis of the effects of coordination of gas and permit market policies can make Russia either a more or a less aggressive competitor in the gas market, depending on the sign of $\partial q/\partial x_g^c$. Such strategic effects will shift profits among the gas suppliers (as well as affecting total profits in the gas market). Hence, coordination is more than a mere internalisation of pecuniary externalities among the Russian gas and permit exporters. While the pure internalisation of pecuniary externalities will clearly be profitable, the profit effects of changing the rule of the game in the gas market are less obvious. In this section, we first discuss why the strategic effect may either reduce or enhance the profits of the Russian gas supplier. We then show that the reduction in profits may be strong enough to make coordination unprofitable.

It is well known that in the Cournot game, each of the agents could increase his profit if he could credibly announce a marginally higher quantity than the Cournot equilibrium quantity. The marginal profit of an increase in the pre-announced quantity will be positive until the Stackelberg equilibrium quantity is reached. Beyond this point, marginal profits of a further expansion of supply will be negative (e.g., Varian (1992)). Any action that alters a firm's marginal costs of production will credibly change the optimal output

[6] The required subsidy s per unit of gas production is given by $p_g - e_g q + s = p_g - e_g c'$, implying that $s = e_g(q - c')$.

level. If the action reduces marginal costs, the firm's output increases (for any given level of the other firms' output). In the Cournot game, a higher output from one of the firms yields lower output from the other firms, which again has a positive impact on the profit of the firm that initially increased its output. An action is said to have a positive strategic effect if the other firms' responses to the action increase the profit of the firm taking the action. If, on the other hand, the other firms' responses decrease the firm's profit, the action is said to have a negative strategic effect (e.g., Tirole (1988), chapter 8). In addition to the strategic effect, an action has also a direct effect on the profit of the firm taking the action. This direct effect captures the impact on the profit for a given output by the other firms. The action is profitable as long as the sum of the direct and strategic profit effects is positive.

In our model, the direct effect on profits of coordinating gas and permit exports is clearly postive, since coordination will internalise the externalities between gas producers and permit suppliers. (We ignore any extra costs associated with the administration of a coordination policy). There is also a strategic effect, since coordination in our model will alter the coordinating gas producers' marginal costs of production. However, the strategic effect contributes positively to profits if and only if the coordination policy makes Russia a more aggressive gas supplier.

Proposition 6 *Assume that $y > 0$. The strategic effect then contributes negatively (positively) to Russia's profit from gas production if increased gas supply reduces (increases) the price of permits ($\partial q/\partial x_g^R < 0$ ($\partial q/\partial x_g^R > 0$)).*

Proof. When $y\partial q/\partial x_g^R < 0$, it follows from Eq. (21) and the second order condition ($\partial^2\pi^R/\partial \left(x_g^R\right)^2 < 0$) that the coordination policy will imply a reduction in x_g^R for a given level of y and x_g^N. It then follows from standard results in the literature that the strategic effect is negative. The opposite result is obtained when $y\partial q/\partial x_g^R > 0$. ■

When increased gas supply decreases the price of permits, coordination of gas and permit market policies will make Russia a less aggressive competitor in the gas market. Since a higher permit price increases permit revenues, coordination will increase the Russian gas supplier's marginal cost and therefore decrease the optimal x_g^R (for given levels of y and x_g^N). In this case, coordination will have a negative strategic effect on Russia's profit. The opposite result is obtained if increased gas supply increases the permit price.

Proposition 7 *Assume that $y > 0$. The coordination policy is profitable if increased gas supply increases the price of permits ($\partial q/\partial x_g^R > 0$).*

Proof. The coordination policy is profitable if the sum of the strategic effect and the direct effect is positive. If $\partial q/\partial x_g^R > 0$, the strategic effect is positive (see proof of previous proposition).The direct effect equals the benefit of internalising the externality between the Russian gas and permit exporters, which is clearly non-negative. ■

If increased production of gas leads to a higher permit price, coordination implies lower marginal production cost in the gas market and hence an increase in gas production. This will increase Russia's total profit for two reasons. First, Russia gains a larger market share in the gas market, which increases its profit in the gas market. Second, the coordinating policy has optimally internalised the externalities in the two markets.

Our next question is whether a negative strategic effect may reduce profits so much that it more than outweighs the benefits of internalising the externality between the Russian gas and permit exporters and thus makes coordination unprofitable.

Proposition 8 *Coordination of gas and permit market policies might be unprofitable if the strategic effect is negative.*

Proof. An example will suffice. Let the direct demand functions for gas and alternative energy be

$$x_i(p_i, p_j) = 1500 - p_i + bp_j, \; i, j = a, g, \; i \neq j, \tag{25}$$

implying the indirect demand functions

$$p_i(x_i, x_j) = \frac{1}{1 - b^2}\left[(1 + b)\,1500 - x_i - bx_j\right], \; i, j = a, g, \; i \neq j, \tag{26}$$

Let $e_g = 0.5$, $d(q) = 0$, $c(y) = .5y^2$, and $\tilde{c}(x_a) = .005x_a^2$. By using Eq. (35) it can then be shown that

$$\frac{\partial q}{\partial x_g^c} = \frac{.5 - be_a}{e_a^2\,(1 - b^2)} \tag{27}$$

Assuming that $b \in [0, 1]$, Eqs. (27) and (21) show that coordination will put Russia at a strategic disadvantage when $be_a > 0.5$, implying that $e_a > 0.5$. Assume that $e_a = 0.6$. Let s denote the emission constraint expressed as the share of the baseline emission level ($s \in [0, 1\rangle$). We now calculate the profit gain from coordination for different levels of b and s. The results are shown in Figure 2.

When $e_a = 0.6$, coordination creates a strategic disadvantage if $b > 0.833$ (see Eq. (27)). We find that coordination will reduce profits for $b > 0.836$. If e_a is raised to .8, a strategic disadvantage is created for $b > 0.625$. In

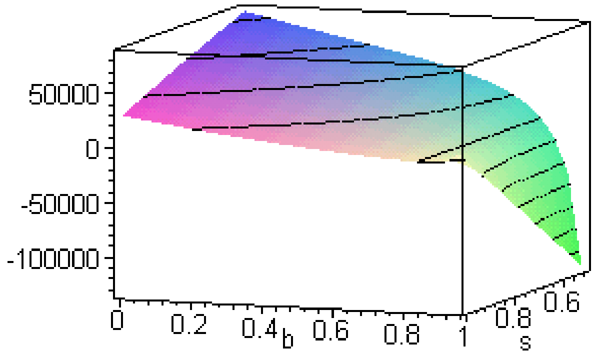

Figure 2: Coordination may be unprofitable

this case, coordination will reduce profits for $b > 0.629$. If both cases, the threshold level b is independent of s.[7] ■

Besides demonstrating that coordination may be unprofitable, these simulation results also demonstrate the crucial importance for the profitability of coordination of the degree of substitution with alternative fuels and of the pollution intensity of these fuels. In general, a high degree of substitution with a highly polluting substitute tends to reduce the profitability of coordination, because the price of permits then tends to fall as gas supply is enhanced.

7 Concluding remarks

We have demonstrated that the impact of monopoly power in the permit market may have an ambiguous impact on the price of permits once we take into account that permit exporters may also be involved on the seller side of non-competitive fuel markets. Hence, it is not obvious that Russia's potential market power in the market for greenhouse gas emission permits will increase the equilibrium permit price.

We have also shown that coordination of supply decisions in fuel markets and in the market for permits will have strategic impacts in non-competitive fuel markets. Whether or not the strategic effect is positive for the coor-

[7]Simulation details are available upon request.

dinating agent depends on how increased output of fuels affects the price of permits, which again depends on the substitution possibilities between alternative fuels and on the relative emission intensities.

Coordination is always profitable if the strategic effect is positive, but may be unprofitable otherwise. A negative strategic effect may reduce profits by more than the increase in profits caused by the internalisation of the externalities between fuel and permit suppliers.

Whether or not Russia's export of greenhouse gas emission permits will actually be coordinated with the export of fossil fuels depends both on the profitability of such coordination and on the possibilities of practical implementation. The latter issue is primarily a question about political will, because there are few practical difficulties with allocating all emission permits in Russia to the leading fuel producers (e.g., Gazprom). Such an allocation would make it quite likely that coordination will actually take place.

To assess the profitability of coordination would require empirical investigations beyond the scope of this paper. Nevertheless, it is of interest to note that the expected export of emission permits from Russia following the implementation of the Kyoto Protocol has the same order of magnitude as the Russian export of natural gas (measured in CO_2 equivalents). This suggests that considerations about the impact on fuel prices will be of considerable importance for the decisions about the level of permit exports. It is also worth noting that it seems likely that increased supply of Russian natural gas might reduce the price of emission permits, because much of this gas probably will replace pollution-intensive coal in European power stations. If the price of permits declines with Russian gas exports, coordination of gas and permit supply will put Russia at a strategic disadvantage in the gas market. That coordination may be unprofitable therefore seems to be more than a theoretical possibility.

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