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Abstract:

I analyze horizontal agreements about the use of a natural resource. I consider a Cournot duopoly where production depends on two inputs, a natural resource and a basket of other resources, according to a production technology with constant returns to scale. I compare three regimes. (1) The competitive benchmark is defined such that firms operate with the cost-minimizing input combination. (2) A joint absolute usage target lowers the absolute usage of the natural resource. It also lowers the usage in relative terms, per unit of production, except with a fixed-proportions production technology. (3) A joint relative usage target mimics the competitive benchmark.

Keywords: Horizontal Agreements, Natural Resources

JEL Classification: L13, L41, Q01, Q38

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1. Introduction

The transition towards more sustainable production practices, which better protect the environment and conserve natural resources, is widely being recognized as a critical and pressing challenge. Governments can use regulation and public investments to drive this transition. Furthermore, a recent debate asks whether competition policy can be instrumental to facilitate sustainability initiatives by corporations (OECD (2020)). Agreements between horizontal competitors are particularly contentious. The European Commission (2021, 2022) is currently revising its guidelines on horizontal cooperation agreements and proposes a new chapter on sustainability agreements. Agreements need to be indispensable for their claimed benefits and the European Commission adopts a consumer welfare standard. Furthermore, competition should be preserved in respect of a substantial part of the products in question. Sustainability agreements between producers in the food industry are exempted from Article 101 TFEU but do need to satisfy indispensability. Several competition authorities worldwide, for example in Australia and South Africa, also incorporate sustainability considerations in their assessments.[1]

Schinkel and Spiegel (2017) and the subsequent studies Schinkel and Treuren (2021) and Schinkel et al. (2022) view sustainability as a dimension of quality. They consider models where firms can invest in sustainability to raise the willingness to pay of consumers. A higher investment makes a firm more aggressive in the product market. Horizontal coordination with respect to investments in sustainability induces firms to consider the negative effect of investing on each other's profit. Investments in sustainability are found to *decrease* whenever spillovers are unlikely. This result is consistent with the literature on R&D cooperation (d'Aspremont and Jacquemin (1988)). It indicates that sustainability agreements are often counterproductive with respect to their claimed benefits. In this case the question of how to quantify sustainability benefits is redundant. Furthermore, in many jurisdictions, horizontal cooperation with respect to R&D is already permitted in the presence of sufficient spillovers.[2]

In this paper I present a model which focuses on the production function of firms instead of the willingness to pay of consumers. I consider a symmetric Cournot duopoly where each firm's production depends on the combination of two inputs, a natural resource (e.g. water or raw

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[1] Holmes et al. (2021) offer a collection of perspectives.
[2] Castroviejo et al. (2021) discuss the role of spillovers in the context of green agreements.

materials) and a basket of other resources (e.g. reproducible capital and labour), according to a Cobb-Douglas production technology with constant returns to scale. The competitive benchmark is defined such that each firm selects its production unilaterally and operates with the cost-minimizing input combination. Within this framework I investigate the effects of permitting firms to horizontally coordinate their usage of the natural resource.

My analysis distinguishes two types of usage targets. First, I consider the effects of permitting firms to jointly set an *absolute usage target*, which defines the total usage of the natural resource per firm. Second, I analyze what happens when firms jointly set a *relative usage target*, which formulates a usage intensity per unit of production. My main result is that permitting horizontal coordination with respect to an absolute usage target reduces the absolute usage of the natural resource. Furthermore, it also decreases the relative usage of the natural resource. A joint relative usage target, however, does not lower the usage of the natural resource, not even in relative terms.

Both ways of measuring the usage of natural resources are relevant in practice. As an example, the European Plastics Pact, which is signed by major companies as well as governments, specifies an *absolute* target to reduce by 10% the usage of "virgin plastics" which are newly made from raw materials (Waste and Resources Action Programme (2020, p.5)). Also, goals to reduce greenhouse gas (GHG) emissions[3] are sometimes specified in absolute terms. To take one example, the furniture company IKEA reports the overall goal "by 2030, to reduce the absolute GHG emissions from the IKEA value chain by at least 15% compared to 2016" (IKEA (2020, p.29)). In the electronics sector, Apple's environmental progress report documents various indicators of its operations such as natural gas usage, emissions, amount of hazardous waste, and paper usage, all measured in absolute numbers. (Apple (2021, p.89)). In contrast, a *relative* target to reduce emissions can be found in the Global Cement and Concrete Association (2021, p.4), which outlines a "proportionate reduction in CO2 emissions of 25% associated with concrete by 2030", where proportionate is defined as relating to per unit of product. As another example, the giant brewing company Anheuser-Busch InBev operates with a water use efficiency target of 2.5 hectoliter per hectoliter of production (AB Inbev et al. (2022, p.17)). The purpose of this paper is to ask what happens when firms are permitted to enforce such targets by means of a horizontal agreement: would the usage of the natural resource be any lower than in the competitive benchmark?

[3] We can view emissions (clean air) as an input in the production function.

In section 3 I establish that permitting firms to horizontally coordinate their absolute usage of the natural resource induces them to use a lower absolute amount. The effects of restricting the absolute usage level of the natural resource can be understood in two steps. First, *fixing* the absolute usage level of the natural resource at the level of the competitive benchmark does not change the marginal cost of producing the equilibrium quantity of the competitive benchmark. However, it causes the marginal cost curve in the product market to be upward sloping, because of diminishing marginal returns with respect to the basket of other resources.[4] Second, *lowering* the absolute usage of the natural resource decreases the productivity of the basket of other resources, which raises the marginal cost function and increases its slope. The increase in marginal cost (which induces a reduction in production quantities) is greater than the increase in average cost. This feature makes it profitable for firms to select an absolute usage level of the natural resource which is lower than that in the competitive benchmark.

Furthermore, the joint absolute usage target also reduces the usage of the natural resource in relative terms, per unit of production. The underlying intuition runs as follows. There is only horizontal coordination with respect the absolute usage of the natural resource but not with respect to the basket of other resources. Firms still compete in production quantities by expanding their usage of the basket of other resources. The basket of other resources ends up being used with a higher intensity per unit of production and the natural resource is used with a lower intensity. This means that the absolute reduction in usage of the natural resource resulting from horizontal coordination is not only driven by the reduction in output; it is strengthened by a reduction in usage per unit of production.

When there is a negative externality associated with using the natural resource, the reduction in usage induced by the joint absolute usage target yields a welfare benefit. How large does the externality need to be such that the benefit of the reduced usage dominates the loss of consumer welfare caused by the output reduction? I report the required externality for various parameter values in my model. In a simple calibration I obtain that the per unit usage externality would need to be about as high as the market price of the natural resource itself.

I also conduct a comparison with full collusion whereby firms coordinate not just their use of the natural resource but also their production quantities. With full collusion, firms operate with the input mix which minimizes their costs, just as in the competitive benchmark. This means

[4] The intuition behind the property of diminishing returns is that, when a firm increases its use of the basked of other resources, each unit of the basked of other resources can be combined with a smaller amount of the natural resource.

that, in contrast with the joint absolute usage target, full collusion is not able to decrease the relative usage of the natural resource. I perform a numerical exercise which indicates that the joint absolute usage target compares favourably against full collusion, on two fronts. It achieves a greater reduction in absolute usage of the natural resource. Furthermore, industry output is higher than with full collusion.

Section 4 studies the regime whereby firms jointly select a relative usage target for the natural resource. Here I show that firms jointly select the same relative usage level as they adopt in the competitive benchmark. Consequently, permitting a joint relative usage target has no effects. Why don't firms jointly determine a relative usage which is lower than that in the competitive benchmark? A lower relative usage would increase the marginal cost of production. Consequently, it would induce firms to produce lower quantities, an effect which is desirable for the firms. However, the average production cost would increase by the same amount as the marginal production cost. The reason is that firms use the identical input combination per unit of production irrespective of how much they produce. Firms prefer the lowest possible production cost, even though a higher one would induce a reduction in production quantities.

The Dutch consumer and market authority, in its revised draft guidelines on sustainability agreements, describes a hypothetical example whereby beverage companies agree about "using a certain weight percentage of recycled materials in the production of beverage packaging" (ACM (2021)). It argues that such a collaboration would produce benefits for the environment. My analysis challenges such a presumption as it predicts that firms would adopt the same weight percentage with or without the sustainability agreement.

Section 5 is devoted to extensions and robustness. I present two insights. Firstly, when the natural resource and the basket of other resources are perfect complements in the production process, the joint absolute usage target mimics full collusion. In this case the joint absolute usage target essentially eliminates all competition. It would thus fail to satisfy Article 101(3) TFEU or similar provisions in other jurisdictions. Secondly, I consider the possibility of a green technology which does not rely on the natural resource at all. Firms can impose the green technology by setting a target of zero usage of the natural resource. Assuming constant returns to scale, I find that firms do not want to set a joint target of zero usage, unless they would also operate with the green technology in the competitive benchmark. This means that the joint target of zero usage does not make firms more environmentally ambitious.

My paper is not the first to show that industries can have incentives to self-regulate. The environmental economics literature has highlighted the characteristic of limited availability of a common-pool resource (Ostrom (1990)). For example, Colombo and Labrecciosa (2018) study cooperation between sellers of a common-pool resource in a dynamic framework. They show that cooperation mitigates the tragedy of the commons and can raise discounted consumer welfare. Inderst et al. (2022) investigate a model where consumers have norm-based preferences. The utility function of consumers depends on the expected market share of the sustainable product variant. Firms can have an incentive to coordinate on the sustainable product variant whenever doing so enables them to sufficiently expand their aggregate market share. If this condition is not satisfied, firms can have an incentive to coordinate on the non-sustainable product variant. Maxwell et al. (2000) and Dawson and Segerson (2008) focus on the interaction between self-regulation and government regulation. They highlight that self-regulation can have the strategic purpose to pre-empt government regulation. Dawson and Segerson (2008) also analyze the incentive of individual firms to participate in a voluntary agreement. All these papers focus on aspects which are different from the one I study.

Maloney and McCormik (1982) is more closely related by analyzing how environmental quality regulation in a competitive industry affects producer welfare. Their analysis shows that a regulation (for example an input restriction) can benefit producers if it makes the average cost curve more inelastic.[5] I investigate horizontal agreements about the usage of a natural resource in a framework of imperfect competition. I show that, to be effective, an agreement needs to specify the usage target in absolute terms. Permitting a joint relative usage target does not make firms more environmentally ambitious. I also obtain that a joint absolute usage target mimics full collusion when the production technology necessitates the natural resource in a fixed proportion. In this case, for example the condition in Article 101(3) TFEU, that competition is preserved in respect of a substantial part of the products in question, would not be satisfied.

Even though plain cartelization is typically illegal, several studies have reported circumstances where it can yield an environmental benefit. Buchanan (1969) discusses the role of market structure when output generates a negative externality. He points out that there can be a welfare benefit from monopolization and discusses the effects of a tax. Ahmed and Segerson (2011)

[5] Vehviläinen (2022) conducts a detailed empirical analysis of a biodiversity regulation which reduces hydropower capacity in Finland. He focuses on competitive bidding strategies and shows that the regulation would raise producer welfare.

develop a model with a brown and green product variety. Their analysis shows a joint incentive for firms to directly restrict their quantities offered of the brown product. Schinkel and Spiegel (2017), in their framework where sustainability is a dimension of quality, find that a production agreement (semi-collusion in the product market) can enhance sustainability investments.

2. Competitive Benchmark

I consider an industry consisting of two identical firms. Each firm i (with $i = 1, 2$) simultaneously decides about its usage of a natural resource (n_i) and its production quantity (x_i). I focus on a standard Cournot setting with homogenous products. Specifically, the inverse demand function equals

$$p = 1 - x_1 - x_2 . \quad (1)$$

The willingness to pay of consumers does not depend on the combination of inputs which is used to make the product. This means that, if there is a negative externality associated with the usage of the natural resource, it is not understood or internalized by consumers.[6]

The production of firm i depends on its use of the natural resource and its use of a basket of other resources (m_i), according to the following Cobb-Douglas production function with constant returns to scale:

$$x_i = \sqrt{n_i m_i} . \quad (2)$$

The market price at which the natural resource can be purchased is exogenous[7] and equal to $c/2$, whereby $0 < c < 1$. Furthermore, the market price of the basket of other resources is also equal to $c/2$.

These assumptions make it optimal for firms to use the two inputs in equal proportions, which simplifies the analysis. Formally, the cost-minimizing way to produce x_i is to select an

[6] I refer to Schinkel and Spiegel (2017) for an analysis when investments in sustainability raise the willingness to pay of consumers.
[7] This means that firms do not enjoy buyer power. Limiting the usage of the natural resource does not induce a reduction in its market price.

absolute amount of the natural resource equal to $n_i = x_i$, which corresponds to a relative usage of the natural resource equal to $\frac{n_i}{x_i} = 1$. Since the usage of the basked of other resources then also equals $m_i = x_i$ (by (2)), the total marginal production cost equals c. The analysis of the competitive benchmark thus turns into that of a standard Cournot model with linear costs. The twist is that the constant marginal cost is not exogenous but results from firms optimizing their input mix.

Denote the production quantity per firm in the competitive benchmark by x^{CB}, the associated usage of the natural resource per firm by n^{CB}, and the profit per firm by π^{CB}.

Result 1. *In the competitive benchmark, each firm*

- *uses an absolute amount of the natural resource equal to* $n^{CB} = \frac{1-c}{3}$*;*
- *uses a relative amount of the natural resource equal to* $\frac{n^{CB}}{x^{CB}} = 1$;
- *produces a quantity equal to* $x^{CB} = \frac{1-c}{3}$*;*
- *earns a profit equal to* $\pi^{CB} = \frac{(1-c)^2}{9}$.

The above Result 1 presents a characterization of the competitive benchmark, focusing on the absolute and relative usage levels of the natural resource, the symmetric production quantity (which determines consumer welfare), and the profit per firm.

3. Joint Absolute Usage Target

In this section I analyze the effects of permitting firms to set the absolute amount of the natural resource used per firm with the objective of maximizing their joint profit. I focus on symmetric agreements whereby $n_1 = n_2 = n$, so that firms can implement the agreement without making side payments.[8] The total usage of the natural resource in the industry equals $2n$.

I begin by characterizing the marginal cost function in the product market for a given value for n, in subsection 3.1. Subsection 3.2 analyzes the production quantities in equilibrium. Subsection 3.3 characterizes the jointly optimal value for n and conducts a comparison with the competitive benchmark. I also explore the welfare effects and present the comparison with full collusion.

3.1 The marginal cost function

Taking as given the value for n, the production quantity of a firm is determined by its usage of the basket of other resources (m_i). Specifically, by (2), the amount of other resources firm i needs in order to produce x_i equals $m_i = \frac{x_i^2}{n}$. Multiplying by the market price of the basket of other resources ($c/2$), we obtain that the variable cost function (which excludes the cost of the natural resource as that cost is determined by the value for n) equals $\frac{c}{2n} x_i^2$. The variable cost function depends negatively on n because using the natural resource lowers the amount of other resources needed to produce a given quantity. The associated marginal cost function equals $\frac{c}{n} x_i$.

[8] By (2), an asymmetric agreement which prohibits one of the firms from using the natural resource makes the other firm a monopolist. Such an asymmetric agreement would require the monopolist to make a side payment to its potential rival.

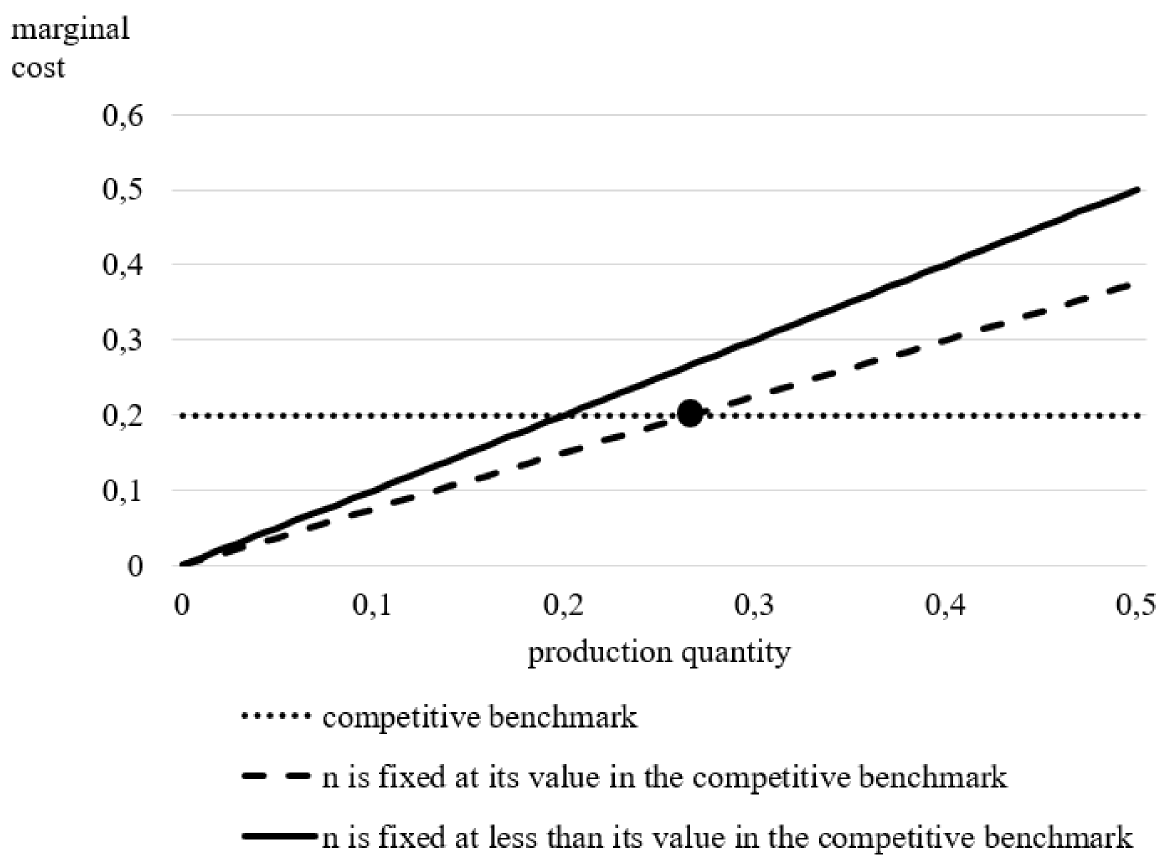

Figure 1: The marginal cost function when firms restrict their absolute usage of the natural resource.

Figure 1 illustrates the marginal cost function when firms restrict their absolute usage of the natural resource. The dotted line displays the marginal cost in the competitive benchmark, whereby c is set equal to 0.2. The dashed line represents the marginal cost function when n is fixed at the value it takes in the competitive benchmark (n^{CB}). Since $c = 0.2$, that value equals $n^{CB} = 4/15$, by Result 1. The marginal cost to produce the equilibrium quantity of the competitive benchmark (x^{CB}) then equals c, as indicated by the black dot. However, since n is pre-determined, producing a quantity less than x^{CB} involves a marginal cost below c, whereas producing a higher quantity requires to incur a higher marginal cost. Fixing the value for n thus generates an upward sloping marginal cost curve, because of diminishing marginal returns. Finally, the uninterrupted line represents the marginal cost function when n is fixed at a level *below* that in the competitive benchmark, such that $n = 3/15$. The reduction of n raises the marginal cost curve and makes it steeper. For example, producing the equilibrium quantity in the competitive benchmark would then require to incur a marginal cost greater than

c. As the next subsection shows, a lower value for n therefore leads to lower production quantities in equilibrium.

3.2 The production quantities in equilibrium

In light of the analysis in the previous subsection, we can write firm i's profit function as

$$\pi_i = \left(1 - x_i - x_j\right) x_i - \frac{c}{2} n - \frac{c}{2n} x_i^2 \quad \text{with } j \neq i . \tag{3}$$

The first term represents the revenues in the product market. The second term equals the cost of purchasing n units of the natural resource. The third term reflects the variable cost of purchasing the other resources.

The necessary and sufficient first-order conditions for optimization in the product market equal

$$x_i = \frac{1 - x_j}{2 + \frac{c}{n}} \quad \text{for } i = 1, 2 . \tag{4}$$

For a given value for n, each firm produces a symmetric equilibrium quantity, which I denote by x and which is obtained by solving (4).

Lemma 1. *Taking as given the value for n, each firm produces a symmetric equilibrium quantity equal to*

$$x = \frac{1}{3 + \frac{c}{n}} . \tag{5}$$

The equilibrium quantities in the product market are an increasing function of n. This means that firms can reduce the equilibrium quantities in the product market by selecting a lower absolute usage target for the natural resource. It is possible to verify that setting $n = n^{CB}$ mimics the competitive benchmark. Equation (5) enables us to characterize the usage of the natural resource per unit of production, as follows.

Lemma 2. *Taking as given the value for n, the relative usage of the natural resource equals*

$$\frac{n}{x} = 3n + c \,. \tag{6}$$

Restricting the absolute usage of the natural resource (n) induces a reduction in its relative usage ($\frac{n}{x}$) as well. The intuition can be understood as follows. Imagine (for the sake of establishing a contradiction) that firms would operate with the same relative usage as in the competitive benchmark even if they restrict their absolute usage of the natural resource. In such a situation firms would face marginal production cost c but produce lower quantities than in the competitive benchmark. The production quantities would not be in equilibrium. Each firm would have an incentive to raise its production by expanding its usage of the basket of other resources. As a result, the relative usage of the basket of other resources increases and the relative usage of the natural resource decreases.

3.3 The jointly optimal absolute usage level of the natural resource

This subsection characterizes the value of n which maximizes profits. Denote the profit per firm by $\pi(n,x)$. The jointly optimal absolute usage target must satisfy the first-order condition

$$\frac{d\pi}{dn} = \underbrace{\frac{\partial \pi}{\partial n}}_{\text{direct effect}} + \underbrace{\frac{\partial \pi}{\partial x}\frac{dx}{dn}}_{\text{strategic effect}} = 0 \,. \tag{7}$$

There is a direct effect and a strategic effect. The direct effect holds fixed the production quantities and therefore revenues. Consequently, it represents the effect of the absolute usage target on profit which happens through the change in cost. The direct effect can be written using (3) and Lemma 1 as $\frac{\partial \pi}{\partial n} = -\frac{c}{2} + \frac{c}{2}\left(\frac{x}{n}\right)^2$. The strategic effect captures the effect of the absolute usage target on profit which happens trough the change in production quantities. Combining (3) and (5), we can obtain that $\frac{\partial \pi}{\partial x} = -x$ and $\frac{dx}{dn} = c\left(\frac{x}{n}\right)^2$. The necessary first-order condition (7) becomes

$$\frac{d\pi}{dn} = \underbrace{-\frac{c}{2} + \frac{c}{2}\left(\frac{x}{n}\right)^2}_{\text{direct effect}} \underbrace{-xc\left(\frac{x}{n}\right)^2}_{\text{strategic effect}} = 0 \,. \tag{8}$$

Evaluated at the equilibrium of the competitive benchmark, where n is chosen to minimize costs ($n = n^{CB} = x^{CB}$ according to Result 1), the direct effect is zero. This means that there is an unambiguous incentive for firms to reduce n below the level of the competitive benchmark, to induce a reduction in output by the strategic effect. However, when $n < n^{CB}$, the relative usage of the natural resource is too low from the perspective of cost-minimization (Lemma 2). Consequently, an incremental reduction of n has the direct effect of increasing costs. The jointly optimal absolute usage target is determined such that the direct effect counterbalances the strategic effect.

For the purpose of brevity, I denote the jointly optimal absolute usage target per firm as n^{AT}. I refer to the associated production quantity and profit per firm as x^{AT} and π^{AT}, respectively. In the Appendix I show the following result.

Result 2. *Permitting horizontal coordination with respect to the absolute usage level of the natural resource*

- *lowers the absolute usage of the natural resource ($n^{AT} < n^{CB}$);*
- *lowers the relative usage of the natural resource ($\frac{n^{AT}}{x^{AT}} < \frac{n^{CB}}{x^{CB}}$);*
- *lowers the production quantities ($x^{AT} < x^{CB}$);*
- *raises the profit levels ($\pi^{AT} > \pi^{CB}$);*

in comparison with the competitive benchmark.

Whereas producers could mimic the competitive benchmark if they would want to, they find it strictly profitable to restrict the absolute usage of the natural resource. By selecting a lower absolute usage level in comparison to that in the competitive benchmark, firms raise their marginal cost functions in the product market and accordingly offer lower quantities. Consequently, firms have a joint incentive to lower their absolute usage of the natural resource, to decrease industry output (the strategic effect). However, in doing so, firms also induce a decrease in the relative usage of the natural resource (Lemma 2). Restricting the absolute usage of the natural resource therefore makes its relative usage too low from the perspective of cost-minimization (the direct effect). The jointly optimal absolute usage target is determined by these two countervailing effects.

I next explore the welfare implications of the joint absolute usage target, when using the natural resource exerts a negative externality. The negative externality can be interpreted as an out-of-market externality. Alternatively, one can adopt the interpretation of a within-market externality, as long as consumers do not understand or consider environmental impact when making purchasing decisions.[9]

How large does the externality need to be, such that the reduction in absolute usage of the natural resource generates a welfare gain which exceeds the loss of consumer welfare caused by the output reduction? I refer to the cut-off value of the externality which satisfies this condition as the "*required externality*". Table 1 reports the required externality for various values of the parameter c (first column) and the associated price-cost ratio in the competitive benchmark (second column[10]). The required externality is reported per unit of usage of the natural resource (denoted by E, third column[11]) and furthermore as a fraction of the market price of the natural resource ($E/(c/2)$, fourth column).

[9] For example, the European Commission (2022, p.142-143) would normally only be willing to take into account collective benefits that accrue to consumers in the relevant market.

[10] The price-cost ratio in the competitive benchmark is equal to $\left(1-2x^{CB}\right)/c$.

[11] The required externality per unit satisfies that the welfare gain from the reduction in absolute usage $E\left(2n^{CB}-2n^{AT}\right)$ equals the loss of consumer welfare due to the output reduction $0.5\left(2x^{CB}\right)^2-0.5\left(2x^{AT}\right)^2$. It follows that $E=\left(0.5\left(2x^{CB}\right)^2-0.5\left(2x^{AT}\right)^2\right)/\left(2n^{CB}-2n^{AT}\right)$.

marginal production cost in the competitive benchmark	price-cost ratio in the competitive benchmark	required externality per unit of usage of the natural resource	required externality per unit of usage, as a fraction of the market price of the natural resource
c	$\left(1-2x^{CB}\right)/c$	E	$E/\left(c/2\right)$
0.05	7.333	0.050	2.004
0.15	2.889	0.118	1.575
0.25	2.000	0.158	1.264
0.35	**1.619**	**0.178**	**1.017**
0.45	1.407	0.182	0.808
0.55	1.273	0.172	0.627
0.65	1.180	0.151	0.465
0.75	1.111	0.120	0.319
0.85	1.059	0.078	0.184
0.95	1.018	0.028	0.059

Table 1: The required externality per unit of usage and as a fraction of the market price of the natural resource.

In my model the required externality depends on the value of c. De Loecker et al. (2020) estimate an average 1.61 price-cost ratio in the US economy. The value $c = 0.35$, highlighted in bold in Table 1, matches this estimate. With this simple calibration, the required externality as a fraction of the market price of the natural resource is about equal to 1 in my model. A lower (higher) price-cost ratio in the competitive benchmark lowers (raises) this threshold. For example, a price-cost ratio equal to 1.41 reduces the required externality as a fraction of the market price down to 0.8, whereas a price-cost ratio of 2.00 elevates the required externality as a fraction of the market price up to 1.3.

In practice, competition authorities would need to rely on an estimate of the externality associated with the usage of the natural resource. For example, the report by de Bruyn et al. (2017) determines the Dutch external cost of aluminium using a method based on the influential model by Hotelling (1931). The external cost depends on the difference between the private and social interest rate. When the difference is lower (higher) than 2 percentage points, the external cost of aluminium is found to be lower (higher) than its market price.

Finally, I compare the joint absolute usage target for the natural resource with full collusion, whereby firms coordinate not only their usage of the natural resource but also their production quantities. With full collusion, both inputs are being used in equal proportions, because firms adopt the input mix which minimizes their cost.[12] The marginal cost is constant and equal to c. Each firm uses an amount $(1-c)/4$ of the natural resource and offers a production quantity equal to $(1-c)/4$. Whereas full collusion reduces the absolute usage of the natural resource in comparison to the competitive benchmark, it does not reduce the relative usage.

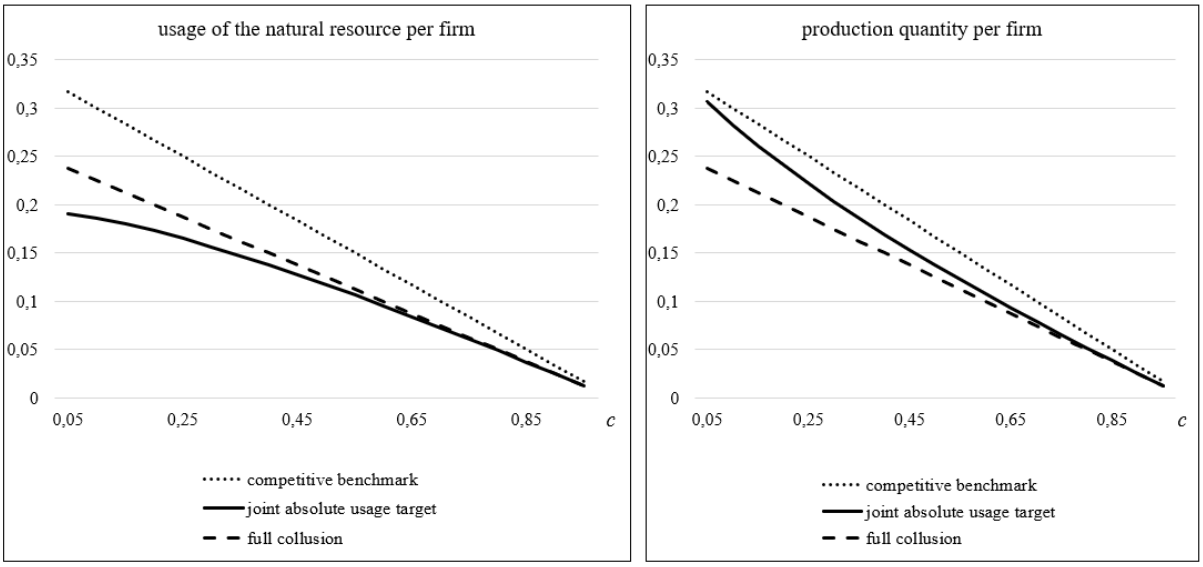

Figure 2: The joint absolute usage target vs full collusion.

Figure 2 compares the joint absolute usage target with full collusion.[13] The left panel illustrates the usage of the natural resource as a function of parameter c. It shows that the joint absolute usage target achieves a greater reduction in usage of the natural resource than full collusion. The right panel illustrates the production quantity per firm. The reduction in production quantity per firm with the joint absolute usage target is less than that under full collusion. The joint absolute usage target thus achieves a greater environmental benefit at lower cost for consumers.

[12] A production agreement, whereby firms only coordinate their production quantities but not their usage of the natural resource, would also induce firms to cost-minimize. Consequently, a production agreement coincides with full collusion in my framework.

[13] The figure is constructed using Results 1 and 2, Lemmas 1 and 2, equation (A4) in the Appendix, and using the expressions in the previous paragraph associated with full collusion.

4. Joint Relative Usage Target

In this section I analyze the effects of permitting firms to jointly select their usage of the natural resource in relative terms, per unit of production. Denote firm i's relative usage of the natural resource by $r_i \equiv \frac{n_i}{x_i}$. I again focus on symmetric agreements whereby $r_1 = r_2 = r$, which do not require any side payments. I will show that firms jointly select a relative usage target such that they mimic the competitive benchmark.

4.1 The marginal cost function

I start by constructing the marginal cost function in the product market which depends on the relative usage of the natural resource r. First, each unit of production is made using r units of the natural resource. Consequently, considering the market price of the natural resource which equals $\frac{c}{2}$, the marginal production cost includes an expenditure equal to $\frac{rc}{2}$ on the natural resource. Second, we can rewrite (2) as $x_i = \sqrt{rx_i m_i}$ or $m_i = \frac{x_i}{r}$, meaning that each unit of production also requires to purchase $\frac{1}{r}$ units of the basket of other resources. Using that the market price of the basked of other resources equals $\frac{c}{2}$, we obtain that there is a need to spend $\frac{c}{2r}$ on the basket of other resources, per unit of production. The effective marginal production cost, which I denote by $e(r)$, is the sum of these two components and equals

$$e(r) = \frac{rc}{2} + \frac{c}{2r}. \tag{9}$$

Notice that the effective marginal production cost $e(r)$ is constant (independent of the production quantity).

4.2 The production quantities in equilibrium

Since the effective marginal production cost given by (9) is constant, the equilibrium production quantity per firm equals the standard expression $\frac{1-e(r)}{3}$.

4.3 The jointly optimal relative usage level of the natural resource

The profit per firm equals $\frac{\left(1-e\left(r\right)\right)^2}{9}$ and is a decreasing function of the effective marginal production cost $e\left(r\right)$. Consequently, firms jointly select r with the objective of minimizing e, given by (9). The first-order condition $1-r^{-2}=0$ is necessary and sufficient and yields that the jointly optimal value for the relative usage target equals $r=1$. I denote the associated absolute usage of the natural resource per firm as n^{RT}, the production quantity per firm as x^{RT}, and the profit per firm as π^{RT}. In light of Result 1, since the joint relative usage target equals $r=1$, it mimics the competitive benchmark.

Result 3. *Permitting horizontal coordination with respect to the relative usage level of the natural resource*

- *does not change the absolute usage of the natural resource (* $n^{RT}=n^{CB}$ *);*
- *does not change the relative usage of the natural resource (* $\frac{n^{RT}}{x^{RT}}=\frac{n^{CB}}{x^{CB}}$ *);*
- *does not change the production quantities (* $x^{RT}=x^{CB}$ *);*
- *does not change the profit levels (* $\pi^{RT}=\pi^{CB}$ *);*

in comparison with the competitive benchmark.

Result 3 implies that permitting firms to jointly set their relative usage of the natural resource is not an effective policy, as firms would jointly select the same relative usage as in the competitive benchmark.

Finally, I mention that Result 3 is robust when the Cobb-Douglas production function takes the more general form $x_i=n_i^{\alpha}m_i^{1-\alpha}$ with $n_i=rx_i$ and $0<\alpha<1$. The associated effective marginal production cost equals $e\left(r\right)=r\frac{c}{2}+r^{\frac{-\alpha}{1-\alpha}}\frac{c}{2}$, where the first (second) term captures the marginal expenditure on the natural resource (the basked of other resources). It is independent of the production quantity. The jointly optimal relative usage target minimizes the effective marginal cost and mimics the competitive benchmark.

5. Extensions and robustness

5.1 Fixed-proportions production function

In this subsection I analyze what happens when the natural resource and the basket of other resources are perfect complements. Specifically, I consider the following fixed-proportions (Leontief) production function:

$$x_i = \min\left\{n_i, m_i\right\}. \tag{10}$$

What are the effects of an absolute usage target per firm equal to n ? When producing a quantity below n, firms face a marginal cost $c/2$ which is equal to the market price of the basket of other resources. However, due to the fixed-proportions production function (10), firms are not able to produce a quantity which exceeds n. This means that the absolute usage target essentially implements a quantity restriction per firm equal to n.

Firms can mimic full collusion by setting an absolute usage target per firm equal to $n = (1-c)/4$ and it is jointly optimal for them to do so. The associated relative usage of the natural resource is equal to 1, the production quantity per firm equals $(1-c)/4$, and the profit per firm equals $(1-c)^2/8$.

Result 4. *Consider the fixed-proportions production function given by (10). A joint absolute usage target for the natural resource mimics full collusion.*

This means that, with a fixed-proportions production function, a joint absolute usage target would not comply with competition law in most jurisdictions.

What are the effects of permitting firms to jointly set a relative usage target for the natural resource? I show that there are no changes in comparison with the competitive benchmark, in line with Result 3. On the one hand, the fixed-proportions production function makes it impossible for firms to operate with a relative usage of the natural resource $r < 1$. On the other hand, firms do not have incentives to select a higher relative usage, because doing so would raise their effective marginal cost. In particular, the effective marginal cost would equal

$e(r) = r\frac{c}{2} + \frac{c}{2}$ whenever $r \geq 1$, reflecting the marginal expenditures on the natural resource (first term) and the basket of other resources (second term). Since profits are decreasing with respect to $e(r)$, as shown in subsection 4.3, the jointly optimal relative usage equals $r = 1$ and firms mimic the competitive benchmark.

5.2 Joint target of zero usage

According to the production functions considered so far, (2) and (10), it is not possible for firms to produce without using the natural resource. A joint target of zero usage would therefore result in zero profits. This means that a joint target of zero usage would not be proposed by the firms.

In this subsection I consider the presence of a green technology which does not rely on the natural resource at all. I ask whether permitting a joint target of zero usage, which imposes firms to switch to the green technology, can induce firms to switch in situations where they would not switch unilaterally. I maintain the assumption of constant returns to scale. Specifically, the green technology is characterized by a constant marginal cost equal to g , which can differ from the constant marginal cost c associated with the conventional technology.[14] When firms are indifferent between switching towards the green technology or not, they make the switch.

In the competitive benchmark, firms operate with the technology which minimizes their cost. Consequently, firms switch to the green technology whenever it is cheaper ($g \leq c$). In this case, permitting a joint target of zero usage has no implications, because firms already make the switch without the horizontal agreement.

When the green technology is more expensive ($g > c$), firms operate with the conventional technology in the competitive benchmark. The profit per firm equals $\frac{(1-c)^2}{9}$. A joint target of zero usage would raise the marginal cost up to g and result in a profit per firm equal to $\frac{(1-g)^2}{9}$. Profits, however, would be lower than in the competitive benchmark because the green

[14] For example, the green technology may rely on different inputs. Furthermore, the costs of certain inputs, such as equity capital or labor, may be different with the green technology than with the conventional technology.

technology is more expensive. Consequently, firms do not have an incentive to set a joint target of zero usage when $g > c$.

Result 5. *Consider the presence of a green technology which makes it possible to produce without using the natural resource at a constant marginal cost. Permitting a joint target of zero usage of the natural resource does not stimulate firms to switch to the green technology.*

Firms would only be willing to propose a joint target of zero usage if they would also operate without the natural resource in the competitive benchmark.

6. Concluding comments

Should competitors be allowed to coordinate their sustainability targets? In this paper I developed a model to analyze horizontal agreements about the use of a natural resource. I showed that a joint absolute usage target induces a reduction in usage of the natural resource. The reduction is both absolute and relative, per unit of production. A joint relative usage target, by contrast, does not change the use of the natural resource. An agreement thus needs to formulate an absolute usage target to be effective.

Firms have an incentive to jointly restrict their absolute usage of the natural resource to induce a reduction in production quantities. This effect harms consumers. Permitting a joint absolute usage target can therefore only be justified if there is a negative externality associated with using the natural resource.

How large should the externality be such that the benefit of lower usage offsets the loss of consumer welfare due to the reduction in production quantities? In a simple calibration I obtained that the usage externality per unit should be about as high as the market price of the natural resource. This requirement is more difficult to satisfy when only consumers in the relevant market can be counted to benefit from the reduced usage. Also, competition authorities should verify that the externality problem is not already addressed by public policies or social norms. I encourage further research on these fronts.

I conclude by highlighting two qualifications. Firstly, caution is required when the natural resource is not at all interchangeable in the production process. In this case I showed that a joint absolute usage target mimics full collusion. Secondly, I assumed that firms need the natural resource to produce. In an extension I explored the incentive for firms to set a joint target of zero usage which imposes a switch to a green production technology. The green technology does not rely on the natural resource. It is characterized by constant returns to scale, just as the conventional technology, although the production cost can differ. In this setup I found no support for potentially permitting a joint target of zero usage.

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Appendix

Proof of Result 2

The proof begins by characterizing the jointly optimal absolute usage level of the natural resource, in steps 1 and 2. Next, steps 3 to 6 conduct a comparison with the competitive benchmark, proving the properties reported in Result 2.

Step 1 (necessary first-order condition). Step 1 simplifies the necessary first-order condition for joint optimality with respect to n, given by (8). The condition can be written as $-1+(1-2x)\left(\frac{x}{n}\right)^2=0$, or

$$(1-2x)=\left(\frac{n}{x}\right)^2.$$

Substituting (5) and (6), we obtain

$$1-\frac{2}{3+\frac{c}{n}}=(3n+c)^2,$$

which becomes $\frac{n+c}{3n+c}=(3n+c)^2$ or

$$(c+3n)^3-(c+n)=0. \tag{A1}$$

Since $c<1$, there exists at lease one positive value for n which satisfies (A1).

Step 2 (uniqueness). Step 2 shows that the necessary first-order condition (A1) has a unique positive solution, by contradiction. Assume that there would be two or more positive solutions. Then (A1) holds for at least two values, which we can denote by a and b, such that

$$(c+3a)^3-(c+a)=0 \tag{A2}$$

and $(c+3b)^3-(c+b)=0$, whereby $0<a<b$. By Rolle's Theorem, there must then exist a value d with $a\le d\le b$ at which the derivative of (A1) with respect to n equals zero, or $9(c+3d)^2-1=0$. Since $0<a\le d$ it must hold true that

$$9(c+3d)^2-1\ge 9(c+3a)^2-1. \tag{A3}$$

Furthermore, by (A2) we can also obtain that $(c+3a)^2=\frac{c+a}{c+3a}$. We can therefore rewrite (A3) as

$$9(c+3d)^2-1\ge 9\frac{c+a}{c+3a}-1,$$

or equivalently $9\left(c+3d\right)^2-1\geq\frac{c+3a+8c+6a}{c+3a}-1$, which becomes

$$9\left(c+3d\right)^2-1\geq\frac{8c+6a}{c+3a}>0$$

and hence contradicts $9\left(c+3d\right)^2-1=0$. We can conclude that (A1) has a unique positive solution, which we denote by n^{AT}, satisfying

$$\left(c+3n^{AT}\right)^3-\left(c+n^{AT}\right)=0. \quad \text{(A4)}$$

Notice that (A4) must imply

$$c+n^{AT}<1. \quad \text{(A5)}$$

The next steps conduct the comparison with the competitive benchmark, proving the four properties reported in Result 2.

Step 3 (absolute usage level of the natural resource). We can rewrite the solution of (A4) as $c+3n^{AT}=\left(c+n^{AT}\right)^{\frac{1}{3}}$ and use from Result 1 that $c+3n^{CB}=1$. By subtracting these two expressions, we obtain $c+3n^{AT}-c-3n^{CB}=\left(c+n^{AT}\right)^{\frac{1}{3}}-1$ or $n^{AT}-n^{CB}=\frac{\left(c+n^{AT}\right)^{\frac{1}{3}}-1}{3}$. The property (A5) now yields that $n^{AT}<n^{CB}$.

Step 4 (relative usage level of the natural resource). Using step 3 and Lemma 2 we can conclude that the relative usage level $\frac{n^{AT}}{x^{AT}}$ is less then the relative usage level in the competitive benchmark $\frac{n^{CB}}{x^{CB}}$.

Step 5 (production quantities). Since $n^{AT}<n^{CB}$ (step 3), we can conclude using (5) that $x^{AT}<x^{CB}$.

Step 6 (profit levels). It can be verified, using Result 1 and Lemma 1, that firms can mimic the competitive benchmark by setting $n=n^{CB}$. Since the jointly optimal value n^{AT} is unique (step 2) and different from n^{CB} (step 3), the possibility to jointly set the absolute usage target strictly raises firms' profits ($\pi^{AT}>\pi^{CB}$).