Horizontal agreements about the use of a natural resource

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I study a class of agreements between product market rivals to restrict their usage of a natural resource. The natural resource serves as an input for production and can imperfectly be replaced by a basket of other resources. The class of permissible agreements includes various quantitative and pricing instruments that fall short of pure price fixing. Under baseline conditions, namely that firms and consumers do not take into account external effects, I characterize the types of restrictions that succeed in breaking the status quo and the types that do not. Agreements that break the status quo reduce the usage of the natural resource but induce firms to set higher prices in the product market. The effect on prices is what motivates firms to make the agreement. Firms prefer the type of restriction that requires as little reduction in usage of the natural resource as possible in order to induce a given price increase. Implications for competition policy are discussed.

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1. Introduction

The conservation of natural resources is widely being recognized as a critical and pressing challenge. It is primarily the responsibility of governments to install appropriate policies and regulation. However, to the extent that governmental efforts may not go sufficiently far, a worldwide debate asks if and how competition policy should be adapted to promote environmental objectives (OECD, 2020, 2021). Agreements between horizontal competitors are particularly contentious. The European Commission (2021, 2023) has published renewed guidelines on horizontal cooperation agreements which include a new chapter on sustainability agreements.[1] Also the Competition & Markets Authority in the UK has now published guidance on green agreements (CMA, 2023).[2]

The existing literature has studied the potential rationale for sustainability agreements in various contexts, such as the presence of a threat of government regulation (Maxwell et al., 2000), consumers being willing to pay more for greener products (Schinkel and Spiegel, 2017), a tragedy of the commons (Colombo and Labrecciosa, 2018), social norms (Inderst et al., 2023), or firm objectives that go beyond profit maximization (Inderst, 2024).

In this paper, I consider a classic oligopoly framework without such considerations, and instead appreciate the wide variety of types of restrictions that firms may agree upon. A question of primary importance, before the discussion about whether competition authorities should incorporate environmental objectives becomes relevant, is whether a joint agreement actually makes firms more environmentally ambitious. In general—as I will make formal in the paper—this happens when the agreement raises marginal costs more strongly than average costs. My main contribution is to characterize, under baseline conditions, the types of restrictions that satisfy this condition and the types that do not. Higher marginal costs induce firms to charge higher prices in the product market and this is what motivates firms to sign

[1] The chapter mentions “limiting the use of natural resources” as an example of a sustainability objective.

[2] Several competition authorities worldwide, for example in Australia and South Africa, also incorporate sustainability considerations in their assessments (Holmes et al., 2021).

the agreement.[3] Note that prices in the product market continue to be chosen unilaterally by the firms, reflecting the illegality of price fixing in most jurisdictions.

A differentiated Bertrand oligopoly model is presented where production happens through the usage of two inputs: a natural resource and a basket of other resources, which are imperfectly replaceable. I consider a class of agreements to restrict the usage of the natural resource. For example, the type of agreement can be such that it restricts the usage of the natural resource measured as a total absolute amount or as a relative amount per unit of production, expands the usage of the basket of other resources (measured possibly in absolute or relative terms), or imposes that the two inputs should be used in a certain fixed proportion. All the restriction types within the class are a homogenous function of the inputs. Internal pricing instruments are also fitted into the framework. The status quo refers to the regime where firms do not make an agreement. My research questions are threefold:

- Does an agreement of a particular type break the status quo?
- If so, what is the effect of the agreement on prices in the product market?
- Which type of agreement carries the preference of the firms?

Real-world examples of sustainability agreements that were permitted are still relatively scarce, perhaps due to the legal uncertainty that has surrounded them up to date.[4] But it is extremely common for firms to operate with environmental targets on an individual basis or through industry associations. 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). In the electronics sector, Apple’s environmental progress report documents various indicators of its operations such as natural gas usage and paper usage, all measured in absolute numbers (Apple, 2021, p.89). An industry-wide target to reduce relative emissions can be found in the Global Cement and Concrete Association (2021, p.4), which outlines a

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[3] The mechanism is related to Salop and Scheffman (1983) who analyze the incentive to raise rivals’ costs as a predatory strategy from the perspective of a dominant firm.

[4] A historic example of an agreement that was allowed is *CECED* where producers of washing machines agreed to abandon the production of the least energy-efficient models. Ahmed and Segerson (2011) provide details about the case as well as a theoretical model.

“proportionate reduction in CO_2 emissions of 25% associated with concrete by 2030”, where proportionate is defined as relating to per unit of product.[5]

If firms want their agreement to be legal on the basis of a sustainability objective, then that objective needs to be credible. In this respect, the new EU Guidelines on horizontal cooperation agreements (2023) state that “A sustainability standardisation agreement is more likely to promote the attainment of a sustainability objective if it provides for a mechanism or monitoring system to ensure that undertakings adopting the sustainability standard comply with the requirements of the standard”. I will thus assume that a joint agreement between firms is enforceable. An alternative interpretation is that firms can tacitly collude with respect to the restriction but not with respect to prices.

Is there an incentive for firms to reduce the restriction level below the level that would prevail under the status quo? A small reduction does not affect the *average* production cost, because the first-order condition for cost-minimization applies. However, the reduction can potentially raise the *marginal* cost of production. Any increase in marginal costs is desirable from the perspective of the firms because it induces them to set higher prices.

That condition, i.e. for marginal costs to increase as a result of a small departure from the status quo, is crucial for a joint agreement to break the status quo. I am able to express this condition in light of the degree of homogeneity of the restriction function. A joint agreement breaks the status quo if and only if a proportional expansion of the usage of inputs leads to a higher level associated with the restriction (reflecting that the restriction function is homogenous of a positive degree). An absolute restriction of the usage of the natural resource clearly satisfies this condition. So does a restriction of the usage of the natural resource relative to the production quantity, whenever the production function is homogenous of a degree less than one (returns to scale are decreasing). In contrast, an agreement that restricts the usage of the natural resource relative to the usage of the basket of other resources does not break the status quo, as in this case firms can expand their usage of both inputs

[5] I follow a strand of literature which models CO_2 emissions as one of multiple inputs (see Holland, 2012, and the references provided therein). A distinct approach is to consider the impossibility of using an alternative input and instead allow for investments in a technology that abates emissions (see Hirose, Lee and Matsumura, 2020).

proportionally while continuing to meet the restriction. I also show that an internal tax on the usage of the natural resource[6] mimics such an agreement that restricts the usage of the natural resource relative to the usage of the basket of other resources. Consequently, an internal tax for using the natural resource does not break the status quo either.

A joint agreement that breaks that status quo raises the prices paid by consumers. This effect is what motivates firms to sign the agreement. The usage of the natural resource is depressed below the usage that firms would desire to choose from the perspective of minimizing costs. Firms would therefore prefer to agree about prices directly, thereby avoiding the need to alter their input mix, if only price fixing were not illegal. Within the set of admissible restriction types (which all satisfy the requirement that the usage of the basket of other resources may not be discouraged), firms prefer to restrict their absolute usage of the natural resource. All other restriction types require stronger substitution away from the natural resource in order to induce a given increase in price.

My analysis, even though it identifies the types of joint agreements that can break the status quo, also illustrates reason for caution. Both the level associated with the restriction as well as the type of restriction are chosen by the firms in a way which is unconnected to the actual environmental externality that results from using the natural resource. This observation stresses the importance of government policy and regulation with the aim of addressing environmental externalities.

An extension of the model analyzes consumer preferences for purchasing from a firm that is more environmentally friendly than its competitors. I show that these preferences erode the ability of a joint agreement to break the status quo. This result is supportive of the UK guidelines (2023) which state that a cooperation agreement is not indispensable where there is sufficient demand for a sustainable product.

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[6] The internal tax inflates the perceived cost of using the natural resource although the tax revenues stay within the industry (for example through lump sum redistributions).

1.1 Related Literature

An extensive literature investigates environmental regulation which is optimal from the perspective of the government. The comparison between various regulatory instruments has been studied, for example, by Spulber (1985), Helfand (1991), Holland (2012) and Hirose and Matsumura (2020). An important insight from this literature, which is echoed in my analysis, is that emission standards which are measured per unit of production tend to lead to higher production quantities and perhaps higher welfare in comparison with absolute standards. However, this literature does not ask whether producers, through joint agreement, would be willing to implement any restrictive standard in the first place.

Only a few studies consider whether environmental regulation can be profitable for firms (Maloney and McCormick, 1982; Akhundjanov and Muñoz-García, 2019; Vehviläinen, 2023). Here Maloney and McCormick (1982) is closest by describing, in a model of perfect competition, a general theoretical condition under which an environmental regulation can enhance the value of firms. However they do not link their condition with the characteristics of the restriction type.

The literature on sustainability agreements has predominantly focused on environmental and ethical considerations on behalf of consumers or firms. Schinkel and Spiegel (2017) and Schinkel and Treuren (2024) view sustainability as a dimension of quality. In such a context, investments in sustainability are found to decrease whenever spillovers are unlikely.[7] This result closely resonates with the literature on R&D cooperation (d'Aspremont and Jacquemin, 1988). Castroviejo et al. (2021) discuss further the role of spillovers in the context of green agreements. Inderst et al. (2023) investigate a different model where consumers have norm-based preferences and Inderst (2024) studies sustainability objectives on behalf of the firms instead of consumers. These contributions can be placed within a broader literature that exists on the relationship between corporate social responsibility and competition (Aghion et al., 2023; Dewatripont and Tirole, 2024).

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[7] Their analysis shows that, in fact, it is a production agreement which could lead to maximal investments in sustainability.

Even though production agreements are illegal in many countries, they can yield an environmental benefit. Buchanan (1969) has pointed out that, when output generates a negative externality, there can be a welfare benefit from monopolization. In my model, the externality is connected to the usage of a natural resource in the production process. Compared with price fixing, I show that restrictions that are specifically targeted towards reducing the usage of the natural resource achieve a bigger reduction in usage of that natural resource, for an equivalent competitive harm.

Section 2 describes the model. Section 3 presents the basic ingredients of the analysis. Section 4 characterizes whether a joint agreement breaks the status quo and provides examples. The choice of type of restriction is analyzed in section 5. Welfare and competition policy are discussed in section 6, whereas section 7 explores what happens when consumers have a preference for environmental welfare. Concluding comments are offered in section 8.

2. The Model

A symmetric oligopoly model is presented. There are n firms. The set of all firms is denoted by $\mathrm{N}=\{1,...,n\}$ where $i \in \mathrm{N}$ and $i \neq j$. Production relies on the usage of two inputs: (i) a natural resource and (ii) a basket of other resources, which are imperfectly substitutable. Denote firm i's usage of the natural resource by x_i and let y_i denote its usage of the basket of other resources.

2.1 Choice of Restriction Level in Stage One

A firm's usage of inputs leads to a level l_i with respect to the restriction, according to the function

$$l_i = R\left(x_i, y_i\right). \tag{1}$$

Throughout the paper, I will denote functions with a capital letter, assume that they are differentiable as many times as needed, and let the subscript 1 (2) denote the partial derivative with respect to the first (second) element. For example, the partial derivatives of $R(x_i, y_i)$ are denoted as $R_1 \equiv \partial R(x_i, y_i)/\partial x_i$ and $R_2 \equiv \partial R(x_i, y_i)/\partial y_i$. With this in mind, I am interested in the following class of restriction types. Let me operate with the convention that a higher restriction level l_i reflects a worse environmental performance.

Assumption 1 (Class of Restriction Types). The restriction satisfies the following properties:

a) $R_1 \geq 0$ (using the natural resource is not encouraged);

b) $R_2 \leq 0$ (using the basket of other resources is not discouraged)[8];

c) $R_1 > 0$ or $R_2 < 0$ (at least one of the above inequalities is strict);

d) $\rho l_i = R_1 x_i + R_2 y_i$ (homogeneity of degree ρ)[9];

e) $l_i = R(x_i, y_i) > 0$ when $x_i > 0$ and $y_i > 0$.

The class of restriction types includes the examples listed in Table 1.

	Restrictions of the usage of the natural resource	Expansions of the usage of the basket of other resources*
Absolute usage	$R = x_i$	$R = 1/y_i$
Usage relative to the production quantity q_i **	$R = x_i/q_i$	$R = q_i/y_i$
Usage relative to the usage of the other input	$R = x_i/y_i$	$R = x_i/y_i$

*Modelled as a restriction of the inverse of the basket of other resources.

**I will assume that the production quantity is a homogeneous function of the inputs.

Table 1: Examples of restriction types encompassed by Assumption 1.

[8] This property explicitly rules out production agreements. For example, the European Commission (2023) as well as the CMA (2023) require that any sustainability agreements must not substantially eliminate competition.

[9] This well-known property is obtained using Euler's Theorem.

Note that a minimum usage of the basket of other resources relative to the usage of the natural resource is equivalent to a maximum usage of the natural resource relative to the usage of the basket of other resources.

At the outset of the game, firms may jointly agree on a restriction level that each firm must adhere to in a symmetrical way, such that $l_i = l$ for all $i \in \mathrm{N}$.[10,11] The set of admissible values for l is a compact interval comprised of strictly positive numbers.[12] The restriction level l is determined with the objective to maximize the joint profit of all the firms in the industry. I will impose regularity conditions that guarantee the existence of a unique optimal value for l, denoted as l^*. For clarity, these conditions will be presented later as we move through the analysis.

Under the status quo (in the absence of an agreement), each firm secretly selects an individual level l_i with respect to the restriction at the outset of the game.[13] I will focus on circumstances where there exists a unique equilibrium restriction level associated with the status quo, denoted as l^{SQ}.

2.2 Product Market Competition in Stage Two

In stage two, every firm i competes in the product market by setting a price for its product in a unilateral way. Products are differentiated in the eyes of consumers. The demand for firm i's product equals

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[10] The focus of the analysis on symmetric restrictions is motivated by the fact that they can be implemented without side payments. Firms may anticipate that any side payment associated with an asymmetric restriction could be problematic as it would raise the suspicion of competition authorities.

[11] Relaxing the assumption that all firms in the industry participate in the agreement is an interesting direction for future research. An analysis of participation constraints in a different setting can be found in Dawson and Segerson (2008).

[12] The bounds of the interval can be determined by a condition that profits must be positive.

[13] Under the status quo, the two stages of the game essentially collapse into one.

$$q_i = D\left(p_i, \overline{p}_{\mathrm{N}\setminus\{i\}}\right), \tag{2}$$

where p_i is the price chosen by firm i (within a compact interval) and $\overline{p}_{\mathrm{N}\setminus\{i\}}$ is the $(n-1)\times 1$ vector of prices chosen by the other firms in the industry.[14] The demand function satisfies $D_1 < 0$ and $D_2 > 0$, where I employ the notation $D_2 \equiv \sum_{j\in \mathrm{N}\setminus\{i\}} \frac{\partial D}{\partial p_j}$. It is assumed that $D_1 + D_2 < 0$ (an identical increase of all prices decreases demand). Demand does not depend on the inputs which are used to make the product. This means that consumers do not understand or care about any environmental effect of their own individual consumption, for example because it is negligibly small.[15]

After the demand q_i for each product i materializes, production takes place subject to the chosen restriction level l_i. The production function is given by

$$q_i = F\left(x_i, y_i\right). \tag{3}$$

Assumption 2 (Production Function). The production function satisfies the following properties:

a) $F_1, F_2 > 0$ (each input contributes positively to production);

b) $x_i q_i^{-1} F_1 < 1$ and $y_i q_i^{-1} F_2 < 1$ (partial output elasticities are less than one)[16];

c) $\varphi q_i = F_1 x_i + F_2 y_i$ (homogeneity of degree $\varphi > 0$)[17];

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[14] The order in which the prices of product market rivals appear in the vector $\overline{p}_{\mathrm{N}\setminus\{i\}}$ is irrelevant because of symmetry.

[15] Section 7 explores what happens when consumers have a preference for environmental welfare.

[16] The first property requires that a percentage increase in the usage of the natural resource increases output by less than a percentage. Likewise, the second property means that a percentage increase in the usage of the basket of other resources increases output by less than a percentage. The reader can verify that Assumption 2b makes sure that all the examples of restriction types presented in Table 1 are consistent with Assumptions 1a, 1b and 1c.

[17] Once again, Euler's Theorem is applied

d) Isoquants are strictly convex.

e) Isoquants are asymptotic to the x_i-axis and the y_i-axis.

The production function exhibits decreasing returns to scale (DRS) when the degree of homogeneity satisfies $\varphi < 1$, constant returns to scale (CRS) when $\varphi = 1$, and increasing returns to scale (IRS) when $\varphi > 1$.

Isoquants are strictly convex (Assumption 2d) if and only if the elasticity of substitution, denoted as

$$\sigma \equiv d\left[\ln\left(x_i/y_i\right)\right] \big/ d\left[\ln\left(F_2/F_1\right)\right], \tag{4}$$

satisfies $0 < \sigma < \infty$. The elasticity of substitution measures (at a specific combination of inputs) the percentage change in the ratio of inputs induced by a percentage change in the ratio of marginal products along an isoquant. The extreme cases of $\sigma = 0$ (reflecting perfect complementarity in a production process à la Leontief) or $\sigma = \infty$ (reflecting perfect substitutability) are ruled out. Note that Assumption 2d encompasses a fairly general class of production functions, as it does not require the elasticity of substitution to be constant.

Lemma 1 (Invertibility). Consider any of the examples of restriction types $R\left(x_i, y_i\right)$ which are presented in Table 1. For any given production quantity $q_i > 0$ and restriction level $l_i > 0$, there exists a unique combination of inputs $\left(x_i, y_i\right)$ which yields the production quantity $q_i = F\left(x_i, y_i\right)$ and adheres to the restriction level $l_i = R\left(x_i, y_i\right)$ at the same time.

In light of Lemma 1, which is proven in the Appendix, let us focus on situation where the input combination $\left(x_i, y_i\right)$ can indeed be pinned down based on the production quantity q_i and the level l_i. The associated functions are denoted as

$$\begin{cases} x_i = X\left(q_i, l_i\right) \\ y_i = Y\left(q_i, l_i\right). \end{cases} \tag{5}$$

The cost function of firm i becomes

$$C\left(q_i, l_i\right) = p^x X\left(q_i, l_i\right) + p^y Y\left(q_i, l_i\right) \ , \tag{6}$$

where the prices of the inputs are denoted as p^x and p^y, respectively. For simplicity, the prices of the inputs are considered to be exogenous.[18,19] The values for p^x and p^y are sufficiently low such that firms can profitably operate in the market.

The profit function of firm i equals the difference between revenues and costs:

$$\Pi\left(p_i, \overline{p}_{N\setminus\{i\}}, l_i\right) \equiv p_i D\left(p_i, \overline{p}_{N\setminus\{i\}}\right) - C\left(D\left(p_i, \overline{p}_{N\setminus\{i\}}\right), l_i\right). \tag{7}$$

Observe that the only channel through which the profits of the firms are interdependent is the demand for a firm's product which is affected by the prices charged by the other firms in the industry. Firm i's profit does not depend in a direct way on the performance of other firms with respect to the restriction (l_j for $j \neq i$).

Assumption 3 (Regularity Conditions Associated with the Price Equilibrium). The profit function satisfies the following properties:

a) $\Pi_{11} < 0$ (existence of a price equilibrium);

b) $\Pi_{12} > 0$ (prices are strategic complements)[20,21];

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[18] This assumption seems reasonable whenever the product market in question is small compared with the markets for inputs. The assumption is similar to that of a "small country" in many models of international trade. It is worth relaxing in future research.

[19] I will think of the price of the natural resource such that it may include an environmental tax per unit. One could furthermore think of firms incurring an intrinsic cost per unit of usage (reflecting "narrow" preferences for sustainability in the terminology of Inderst, 2024) and the main results would be unaffected.

[20] Consistent with earlier notation, I define $\Pi_{12} \equiv \sum_{j \in N\setminus\{i\}} \frac{\partial \Pi_1}{\partial p_j}$.

[21] In an earlier working version of this paper, I operated with a Cournot model where quantities are strategic substitutes that delivered similar insights.

c) $\Pi_{11} + \Pi_{12} < 0$ (uniqueness and stability of the price equilibrium).

Assumptions 3a and 3b are familiar. Assumption 3c is a conventional regularity condition which means that the best-reply prices are "contractions" (see Vives, 1999, p. 47). It ensures uniqueness of the price equilibrium as well as stability. A symmetrical restriction level l in stage one (either through agreement or under the status quo) gives rise to a symmetric price equilibrium in stage two, for the following reason. Any asymmetric equilibrium would imply the presence of other asymmetric equilibria with the roles of the firms interchanged, which would contradict uniqueness of the price equilibrium (where uniqueness follows from Assumption 3c).

3. Analysis

I initially analyse the joint agreement followed by product market competition. Next, I will characterize the status quo benchmark.

3.1 Joint Agreement Followed by Product Market Competition

The level l of the restriction (such that $l_i = l$ for every firm i) is chosen with the objective of maximizing the total profits in the industry. The symmetric equilibrium price as a function of the agreed level l is denoted as $P(l)$. Denote the $(n-1)\times 1$ vector of price functions (reflecting the firms other than i) as $\bar{P}(l) = \{P(l),...,P(l)\}$. Since the price equilibrium is symmetric, maximizing the total profits in the industry is equivalent to maximizing the profit per firm. The necessary first-order condition for maximization with respect to l equals

$$\frac{d\Pi}{dl} = \underbrace{\frac{dP}{dl}\Bigg(\underbrace{\Pi_1 + \Pi_2}_{=0}\Bigg)}_{\text{indirect price effect}} + \underbrace{\Pi_3}_{\text{direct cost effect}} = 0. \quad (8)$$

Condition (8) reflects that an increase in the level of the restriction l affects the profit of a firm via two channels. Firstly, it induces a change in the equilibrium price which is charged by all firms in the industry (the “indirect price effect”). Note that $\Pi_1 = 0$ because firms choose their own price in a way that satisfies the first-order condition for maximizing profit (the Envelope Theorem). So the profit of a firm is only affected by the change in price charged by the rivals. Secondly, an increase in the level l affects profits through a direct effect on the cost of the firm (the “direct cost effect”).

As a next step, we characterize the effect of the level l on the equilibrium price. Implicit differentiation of the necessary first-order condition $\Pi_1 = 0$ with respect to l yields

$$\frac{dP}{dl} = -\Pi_{13}\left(\Pi_{11} + \Pi_{12}\right)^{-1}. \tag{9}$$

From (7), we can obtain that

$$\Pi_{13} = -C_{12} D_1 . \tag{10}$$

The effect of the level l on the equilibrium price can now be expressed as

$$\underbrace{\frac{dP}{dl}}_{\substack{\text{change in the equilibrium price} \\ \text{induced by a change in } l}} = \underbrace{C_{12}}_{\substack{\text{change in the} \\ \text{marginal cost} \\ \text{induced by a} \\ \text{change in } l}} \underbrace{D_1\left(\Pi_{11} + \Pi_{12}\right)^{-1}}_{\substack{\text{pass-through} \\ \text{rate "}T\text{"}}}, \tag{11}$$

where the pass-through rate

$$T \equiv D_1\left(\Pi_{11} + \Pi_{12}\right)^{-1} \tag{12}$$

is the rate at which an induced change in marginal cost translates into a change in the equilibrium price. In light of the properties $D_1 < 0$ and Assumption 3c, the pass-through rate T is positive.

By employing (7) and (11), we now write the first-order condition for l^* (given by (8)) more explicitly as follows.

Lemma 2 (Jointly Optimal Restriction Level). The optimal restriction level l^* which maximizes the profit per firm satisfies the first-order condition $\left.\frac{d\Pi}{dl}\right|_{l=l^*} = 0$ whereby

$$\frac{d\Pi}{dl} = \underset{\frac{dP}{dl}}{C_{12}T}\left[\underbrace{D + PD_1 - D_1C_1}_{\Pi_1=0} + \underbrace{D_2\left(P - C_1\right)}_{\Pi_2>0}\right] - C_2. \tag{13}$$

The optimal level l^* which maximizes the profit per firm is the result of a balance between two forces. The first term in (13) captures that a change in the level l can affect the equilibrium price through a change in the marginal cost which is passed through. Remember that the change of the firm's own price does not show up in (13) because such a change is profit-neutral by the Envelope Theorem. However any change in the price charged by the rivals affects the profit of the firm through a change in the demand that it faces for which it earns a profit margin $P - C_1$ (a competitive externality that the rival firms do not take into account in their pricing decisions). The second term in (13) represents the direct effect of changing the level l on the production cost of the firm.

As an alternative characterization, we can decompose (13) into an effect of l on the revenues per firm ($d\left(PD\right)/dl$, the first term in (14)) and costs per firm (dC/dl, the second term in (14)):

$$\frac{d\Pi}{dl} = \underbrace{C_{12}T\left(D + PD_1 + D_2P\right)}_{\frac{d(PD)}{dl}} + \underbrace{C_{12}TC_1\left(-D_1 - D_2\right) - C_2}_{-\frac{dC}{dl}}. \tag{14}$$

We can now present the following regularity conditions which justify our focus on a unique solution for l^*.

Assumption 4 (Regularity Conditions Associated with the Joint Agreement in Stage One).

a) The revenue per firm is a strictly concave function of the agreed level l: $d^2\left(PD\right)/dl^2 < 0$.

b) The cost per firm is a strictly convex function of the agreed level l: $d^2C/dl^2 > 0$.

c) The profit per firm is a strictly concave function of the agreed level l: $d^2\Pi/dl^2 < 0$.

We can interpret Assumption 4a as requiring that the demand function should not be too convex. Assumption 4b reflects the feature that the natural resource and the basket of other resources are imperfect substitutes. Assumption 4c is a direct consequence of 4a and 4b, because the difference between a strictly concave function and a strictly convex function is strictly concave.

3.2 Status Quo Benchmark

The equilibrium under the status quo is characterized by the optimality conditions $\Pi_1 = 0$ (prices are best replies) and $\Pi_3 = 0$ (the restriction levels are best replies). We can employ (7) to rewrite the condition $\Pi_3 = 0$ as $C_2 = 0$, i.e., the level l_i is chosen with the objective to purely minimize the cost of firm i taking as given its production quantity.

Lemma 3 (Restriction Level Under the Status Quo). The restriction level l^{SQ} which prevails under the status quo satisfies the first-order condition

$$C_2\big|_{l^{\text{SQ}}} = 0. \tag{15}$$

Recall our assumption that l^{SQ} is unique. The resulting equilibrium price in the product market equals $P\left(l^{\text{SQ}}\right)$.

4. Does the Joint Agreement Break the Status Quo?

The aim of this section is to characterize whether the joint agreement "breaks the status quo" in the sense that it leads to a restriction level (l^*) which is strictly lower than the level which prevails under the status quo (l^{SQ}).

4.1 A General Condition

Assumption 4c tells us that the profit per firm as a function of l is strictly concave. Hence, the joint agreement succeeds in breaking the status quo if an only if

$$\left.\frac{d\Pi}{dl}\right|_{l=l^{SQ}} < 0, \tag{16}$$

reflecting that there is pressure for firms to restrict the level below l^{SQ}. The condition (16) can be written, by using (13), as follows:

$$\left.\left[C_{12}TD_2\left(P-C_1\right)-C_2\right]\right|_{l=l^{SQ}} < 0. \tag{17}$$

Let us now make two observations. Firstly, a marginal change in l below the level l^{SQ} does not have any direct effect on costs ($C_2 = 0$). We have indeed seen in Lemma 3 that the first-order condition for cost-minimization is satisfied under the status quo. Secondly, the expression $TD_2\left(P-C_1\right)$ is strictly positive under our prevailing assumptions. We can therefore conclude that the condition for the joint agreement to break the status quo simplifies as:

$$\left.C_{12}\right|_{l=l^{SQ}} < 0. \tag{18}$$

The condition (18) says that a marginal reduction in the level l below l^{SQ} strictly raises the marginal cost of production. Higher marginal costs translate into a higher equilibrium price. The increase of the equilibrium price raises the profit per firm.

Proposition 1 expresses condition (18) in light of the degree of homogeneity of the restriction function. It is the main result of the paper and is proven in the Appendix.

Proposition 1 (Condition for Breaking the Status Quo). The joint agreement breaks the status quo if and only if the degree of homogeneity of the restriction function $R(x_i, y_i)$ is strictly positive ($\rho > 0$).

From the perspective of the firms, the motivation for making an agreement is to induce an equilibrium in the product market with higher prices. So an agreement must sufficiently discourage production to break the status quo. Proposition 1 tells us that the condition for this to happen is that the restriction type is homogenous of a positive degree. In this case, expanding the usage of both inputs in a proportional way leads to a higher level l_i (a worse performance with respect to the restriction). A restriction level which is tighter than that under the status quo discourages production (induces firms to raise prices). In contrast, a restriction type which is homogenous of degree zero makes it possible for firms to expand their usage of both inputs in a proportional way, without raising their level l_i. Hence, a jointly agreed restriction does not succeed in breaking the status quo when the restriction function is homogenous of degree zero.

4.2 Application of the General Condition

Proposition 1 can be applied to the restriction types which were presented in Table 1. A jointly agreed restriction of the absolute usage of the natural resource ($R = x_i$) always breaks the status quo, whereas a jointly agreed expansion of the absolute usage basket of other resource ($R = 1/y_i$) never does. In other instances, the production technology may be crucial. For example, a jointly agreed restriction of the usage of the natural resource relative to the production quantity ($R = x_i/q_i$) breaks the status quo if and only if returns to scale are decreasing (DRS). Conversely, a jointly agreed expansion of the usage of the basket of other resources relative to the production quantity ($R = q_i/y_i$) breaks the status quo if and only if returns to scale are increasing (IRS). A joint agreement about the ratio of inputs ($R = x_i/y_i$) never breaks the status quo.

Table 2 presents fictitious examples of types of joint agreements and whether they break the status quo, as predicted by my analysis.

Agreement type	**Example (fictitious)**	**Does the agreement break the status quo?**
restriction of absolute usage of the natural resource	smartphone producers jointly decide to lower their absolute usage of a rare mineral	yes
expansion of absolute usage of the basket of other resources	furniture companies agree to utilize an absolute minimum of a sustainably grown wood type	no
restriction of the usage of the natural resource per unit of production	beverage producers set a maximum usage of water per liter of production	yes if and only if production is characterized by DRS*
expansion of the usage of the basket of other resources per unit of production	the aviation industry agrees to a minimum usage of renewable fuels per passenger/mile	yes if and only if production is characterized by IRS*
usage of the natural resource relative to sum of that usage and the basket of other resources**	the fashion industry agrees to use a maximum percentage of new (non-recycled) fabrics	no
internal tax on the usage of the natural resource***	the shipping industry association collects a per unit tax for CO_2 emissions and redistributes the revenues internally	no
internal subsidy for using the basket of other resources***	manufacturing companies subsidize each other per unit of usage of eco-friendly chemicals	no

*See Remark 1, **See Remark 2, ***See Remark 3

Table 2. Whether various types of agreements break the status quo, based on the analysis.

Remark 1 (Short Run vs. Long Run)

In the short run, firms cannot adjust every input in a flexible way. We may then think of the basket of other resources such that it contains, for example, only labour but not capital. In contrast, all inputs are variable in the long run (by definition of "long run"). The basket of other resources can then be interpreted such that it includes both labour and capital.

It is not implausible to assume that there are constant returns to scale (CRS) in the long run: a proportional expansion of all inputs leads to an expansion of output by the same factor. In the short run, when the usage of for instance capital cannot expand, a proportional increase of only the variable inputs must then lead to a less-than-proportional increase in output (DRS). In light of such a reasoning, we could conclude that the returns to scale are connected to the time horizon of the agreement as follows.

- To evaluate whether a joint agreement that comes into effect in the short run is capable of breaking the status quo, the production technology should be viewed as characterized by decreasing returns to scale (DRS).
- To evaluate whether a joint agreement that comes into effect in the long run is capable of breaking the status quo, the production technology should be viewed as characterized by constant returns to scale (CRS).

Competition authorities can thus identify the presence of any decreasing returns to scale by looking at whether the agreement comes into effect in the short run.

Remark 2 (Agreements about the Input Mix)

There are several restriction types that essentially fix the input mix. For example, agreements that specify the usage percentage of a certain input relative to the combined usage of both inputs ($R = x_i/(x_i + y_i)$ and $R = (x_i + y_i)/y_i$) and agreements specifying the usage of one input relative to the other input ($R = x_i/y_i$) are all homogenous of degree zero. They do not break the status quo.

Remark 3 (Internal Pricing of Inputs)

The final two examples in Table 2 are an internal tax per unit of usage of the natural resource and an internal subsidy per unit of usage of the basket of other resources. With "internal" it is meant that the tax revenue stays within the industry or the subsidy is collected by the industry participants themselves (for example through lump sum transfers). In other words, these pricing instruments merely affect the *perceived* cost of using the natural resource relative to the usage of the basket of other resources. Since firms are behave symmetrically they do not cause an actual financial loss or income.

We know that the ratio of the price of the natural resource relative to the price of the basket of other resource (p^x / p^y) determines the ratio of inputs that firms optimally choose (x_i / y_i). That ratio is independent of the production quantity, because of homogeneity of the production function, as has been shown in Part 4 the Proof of Proposition 1. Pricing instruments therefore make it possible for firms to essentially mimic a joint agreement about the input mix ($R = x_i / y_i$). Note, however, that the change in the input mix is not forced. Rather it is induced indirectly by tweaking the perceived price of the natural resource relative to that of the basket of other resources. Nevertheless, since internal pricing of inputs implements the same effects as a direct agreement of type $R = x_i / y_i$ (which is homogenous of degree zero), we can conclude that it does not break the status quo.

Overall, the above applications illustrate that the precise way in which a joint agreement is formulated matters for whether it succeeds in breaking the status quo. The CMA (2023), in its new guidelines, states that: "An example of target setting agreements that is unlikely to have an appreciable effect on competition would be where the fashion sector agrees targets to increase gradually the amount of sustainable materials used in their clothing ranges [...]". This statement does not specify whether the target is an absolute one ($R = 1/y_i$), refers to a usage percentage as part of the overall input mix ($R = (x_i + y_i)/y_i$), or measures the amount of sustainable materials relative to the production quantity ($R = q_i / y_i$). My analysis predicts that a joint agreement only breaks the status quo if it employs the latter specification and if there are increasing returns to scale (IRS).

4.3 Effects of an Agreement that Breaks the Status Quo

The next proposition, proven in the Appendix, highlights that reducing the usage of the natural resource comes at the expense of consumers as they will face higher prices. A joint agreement that breaks the status quo also induces firms to deviate from cost-minimization: they use a lower amount of the natural resource than would be optimal if the objective was purely to minimize costs. Such an effect would not show up if the agreement was directly to fix prices at the same level.

Proposition 2 (Effects of a Joint Agreement that Breaks the Status Quo). A joint agreement that breaks the status quo induces firms to

a) charge higher prices in the product market ($P\left(l^{*}\right) > P\left(l^{\mathrm{SQ}}\right)$).
b) use a lower amount of the natural resource than would be optimal if the objective was purely to minimize costs ($p^{x}F_{2} - p^{y}F_{1} < 0$).

Figure 1 illustrates the comparison between a joint agreement that breaks the status quo and a “direct” agreement between firms to fix prices at the same level. Point A represents the input combination under the status quo. The isoquant is tangent to the isocost curve which is linear (because the market prices of the inputs are constant). A direct agreement between firms to raise prices is represented by point B. It is located on a lower isoquant and involves a lower usage of the natural resource. However firms continue to produce with the combination of inputs that minimizes their cost of production. The ratio of inputs is preserved (this property follows from homogeneity of the production function, as is shown in Part 4 of the proof of Proposition 1 which is presented the Appendix). A joint agreement that breaks the status quo (represented by point C in figure 1) additionally induces a shift away from the natural resource. It is therefore associated with an even lower usage of the natural resource.

Corollary 1 (Comparison with Price Fixing). A joint agreement that breaks the status quo is associated with a strictly lower usage of the natural resource than a direct agreement between the firms to fix prices at the identical level.

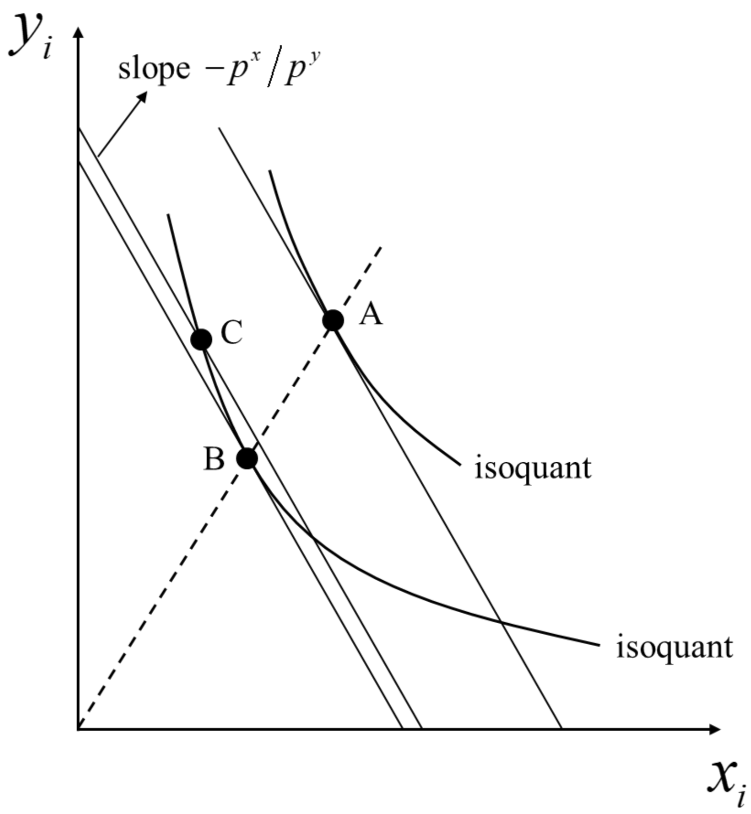

Figure 1: The comparison between a joint agreement that breaks the status quo and a direct agreement between firms to fix prices at the same level.

Notice also that the joint agreement that breaks the status quo (point C) is associated with higher production costs (is located on a higher isocost line) than the direct agreement to fix prices at the same level (point B). We can therefore conclude that firms would prefer to fix prices directly if doing so was not illegal.

5. Choice of Type of Restriction

Since firms can always mimic the status quo by setting $l = l^{SQ}$, restriction types that do not satisfy the condition for breaking the status quo are strictly less attractive for firms than restriction types that break the status quo. But which restriction type will firms choose among all restriction types that break the status quo? In this section I will show that firms prefer to be able to restrict their absolute usage of the natural resource.

The reasoning takes two steps. Firstly, the main step is to show that, given any other restriction that breaks the status quo, firms can strictly raise profits by agreeing on the restriction of absolute usage of the natural resource that leads to the same price equilibrium. Secondly, these profits are an underestimate of the profits that firms can earn when they determine the level of the restriction of absolute usage of the natural resource in a jointly optimal way (instead of merely in a price-equivalent way). The option to jointly re-optimize the level of the absolute usage restriction only strengthens the attractiveness of restricting the absolute usage of the natural resource. I therefore focus my attention on the first step.

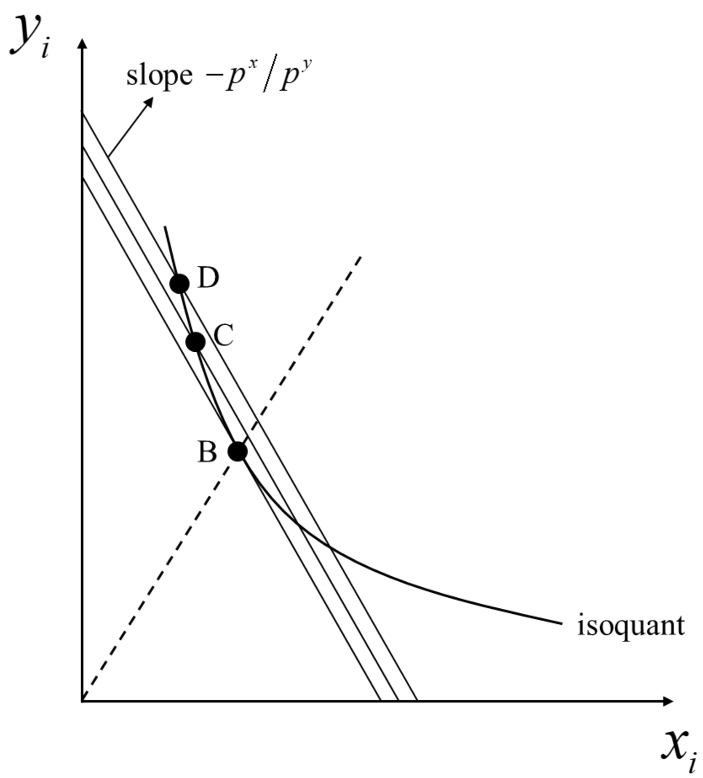

Figure 2: The comparison between two price-equivalent types of restrictions that break the status quo.

Let the restriction of the absolute usage of the natural resource be of type C such that $R_2^C = 0$ (the usage of the basket of other resources has no effect on the restriction level), whereas the other restriction is of type D in such a way that $R_2^D < 0$ (using the basket of other resources contributes to meeting the restriction). By construction, the restrictions lead to the same price equilibrium (that is, they are "price-equivalent") and hence they lead to an identical production quantity per firm. Figure 2 illustrates that the input combinations C and D are indeed located on the same isoquant. In light of revenues being identical, the restriction of absolute usage of the natural resource is more profitable for firms whenever production costs are lower (the input combination is situated on a lower isocost line). Note that both restriction types induce firms to shift away from the natural resource such that $p^x F_2 - p^y F_1 < 0$ (see Proposition 2b). Figure 2 illustrates this property whereby the slopes of the isoquant at points C and D are steeper than the slope of the isocost line. However, I will show that the shift away from the natural resource is less pronounced under restriction C than under restriction D (point D is located higher up the isoquant). Recall that point B represents the input combination associated with a direct agreement between firms to fix prices at the same level. Under such an agreement, firms would choose inputs with the objective of minimizing production costs. At point B, the isocost line is tangent to the isoquant.

Proposition 3 (Choice of Type of Restriction). Among all types of restrictions covered by Assumption 1, firms strictly prefer the option to restrict their absolute usage of the natural resource.

The proof is presented in the Appendix. It shows that firms deviate less from the cost-minimizing input mix under the restriction of absolute usage of the natural resource compared with any other restriction that breaks the status quo. Price-equivalence requires that marginal costs are identical under both restrictions. For this to happen, the following two forces must exactly counterbalance each other.

Force 1. Under the absolute restriction (of type C), expanding production happens solely by increasing the usage of the basket of other resources. Firms are not allowed to increase their usage of the natural resource if they face more demand. In contrast, the other restriction (of type D) has the feature that $R_2 < 0$ which means that using the basket of other resources provides space for firms to increase their usage of the natural resource, while still adhering to the agreed restriction level. The possibility to expand the usage of the natural resource under the restriction of type D should lead to a lower marginal cost of production, if it were not for the presence of the following offsetting force.

Force 2. The restriction of type D is associated with a lower marginal product of the basket of other resources ($F_2^D < F_2^C$). This happens because the usage of the basket of other resources is higher and the usage of the natural resource lower under restriction D, compared with the restriction of type C. Figure 2 illustrates that point D is located higher up the isoquant than point C.

Notice in Figure 2 that the restriction of type D is associated with higher production costs (is located on a higher isocost line) than the price-equivalent restriction of type C. Hence, starting from any joint agreement of type D, firms always prefer to instead agree about restricting their absolute usage of the natural resource in such a way that that the equilibrium price (and hence the production quantity per firm) is unchanged. The option for firms to jointly optimize the level of the absolute restriction only reinforces its attractiveness. Finally, it is worth reiterating Corollary 1 which found that a restriction of absolute usage of the natural resource is still less attractive for firms than a direct agreement to raise prices to the same level (as represented by point B in Figure 2).

6. Welfare and Competition Policy

In this section, I discuss the welfare implications of permitting a joint agreement in light of various possible objective functions on behalf of the competition authority.[22] The market price for the natural resource is the sum of two components: $p^x = c + t$ where c denotes the cost of purchasing a unit of the natural resource (net of tax) and t the environmental tax per unit. Denote the environmental externality associated with using a unit of the natural resource as $e^{\text{ENV}} < 0$.[23] For clarity of discussion, let us focus on the case where the environmental

[22] A separate question, which I do address, is how a government would optimally design its policy, for example if it can choose l as a sole instrument or if it can regulate both l and prices in the product market. A government may also alter the tax t for using the natural resource.

[23] de Bruyn et al. (2017) present methodologies for determining the pollution externality associated with the use of various materials, with the goal of obtaining concrete numbers that can be used for policy analysis.

externality happens completely outside of the relevant market. This assumption is reasonable when consumers constitute only a small portion of the overall population.

The "Out-Of-Market" (OOM) externality, denoted as e^{OOM}, measures the residual externality after the tax has been paid: $e^{\text{OOM}} \equiv t + e^{\text{ENV}}$. I will assume that an OOM externality indeed exists and is negative ($e^{\text{OOM}} < 0$). Such a setup reflects the notion of "residual market failure" which the EU relies upon in its Horizontal Guidelines around sustainability agreements (European Commission, 2023).

Assumption 5 (Out-Of-Market Externality). Using the natural resource brings about a negative externality which happens completely outside of the relevant market. The "Out Of Market" (OOM) externality is constant per unit of usage and equals $e^{\text{OOM}} < 0$.

The discussion below considers four potential objective functions on behalf of the competition authority.

6.1 Consumer Welfare Standard

As Proposition 2 shows, a joint agreement that breaks the status quo leads to higher prices paid by consumers, making them worse off. Competition authorities that adopt a consumer welfare standard would prohibit the horizontal agreement.

6.2 Consumer Welfare Standard Including OOM Externalities

A joint agreement that breaks the status quo reduces the usage of the natural resource. Hence, it mitigates the total externality which is inflicted outside of the relevant market. There is an associated welfare benefit which counteracts the consumer harm resulting from the higher equilibrium price. Competition authorities that include OOM externalities into their assessment would therefore approve of the joint agreement if and only if the OOM externality e^{OOM} is sufficiently negative.

6.3 Sum of Consumer and Producer Welfare Standard

To analyze the effect of a joint agreement that breaks the status quo on the sum of consumer and producer welfare, it is instructive to view the agreement *as if* it is the combination of two separate agreements.

The first step is to imagine that firms would directly agree to increase prices to the same level that prevails after the actual joint agreement about the usage of the natural resource. The equilibrium price would go up in a way that deviates further from the marginal cost of firms. As a result, the sum of consumer and producer welfare decreases.

The second step is to imagine that firms would, in addition to the price agreement, agree to distort their input choices such that they use a smaller amount of the natural resource and a higher amount of the basket of other resources. Such an agreement raises production costs without affecting consumers. Hence, the sum of consumer and producer welfare further declines. We conclude that a joint agreement that breaks the status quo always reduces the sum of consumer and producer welfare.

6.4 Sum of Consumer and Producer Welfare Standard Including OOM Externalities

Incorporating the welfare benefit which happens outside of the relevant market as a result of the joint agreement turns the overall welfare assessment into a positive one whenever the OOM externality is sufficiently negative.

Furthermore, note that including producer welfare into the analysis works in the direction of making the agreement more acceptable for competition authorities, as producers are always a beneficiary of the agreement (they would otherwise not make the agreement in the first place).

The following proposition summarizes the above discussion.

Proposition 4 (Welfare Effects When the Externality Happens Out-Of-Market). A joint agreement that breaks the status quo

a) is not permissible for a competition authority that does not incorporate OOM externalities in its objective function.
b) is permissible for a competition authority that incorporates OOM externalities in its objective function, if and only if the OOM externality per unit of usage of the natural resource (e^{OOM}) is sufficiently negative.

Proposition 4b finds that permitting a joint agreement about the usage of a natural resource can be justified based on a broad welfare criterion. However, this seemingly optimistic conclusion towards permitting a joint agreement comes with two caveats.

Caveat 1. There is no guarantee that firms jointly select the appropriate restriction level l^*. As the OECD background paper (2021) notes, "Such an approach [via competition enforcement] may lead to advancing environmental goals only in specific sectors or to setting a level of cost internalisation that is not the optimal one and still may be prone to abuses." If e^{OOM} equals zero, then the level l which would induce efficient input choices would be that under the status quo (l^{SQ}). An agreement that breaks the status quo will then reduce the usage of the natural resource too much from the perspective of production efficiency (the level l^* associated with the restriction will be too low). Conversely, one can always find an OOM externality e^{OOM} sufficiently high such that the usage of the natural resource is still excessive, even when firms make a joint agreement. The OOM externality, by definition, happens outside of the relevant market. Neither firms nor consumers take it into account. Only by mere coincidence can the jointly optimal l^* reflect precisely the severeness of the OOM externality in order to induce the appropriate usage of the natural resource.

Caveat 2. As we showed in Proposition 3, firms have an incentive to choose the type of restriction which achieves as little substitution away from the natural resource as possible, conditional on prices in the product market. There exist types of restrictions that could achieve a bigger reduction in usage of the natural resource while raising the equilibrium price paid by consumers to the identical level (hence leading to identical consumer welfare). These types of restrictions, however, are not voluntarily chosen by the firms.

Many jurisdictions require that any elimination of competition does not go further than necessary in light of the objective of the agreement.[24] In light of Proposition 3, it could perhaps be argued that the restriction of absolute usage of the natural resource which is chosen by the firms does not meet such a criterion. Then again, other types of restrictions are less profitable for firms, and may not satisfy the condition for breaking the status quo. So the competition enforcer faces a dilemma: either to permit a type of agreement that breaks the status quo but raises prices more than necessary, or to insist on a type of agreement that better protects consumers but which does not provide incentives for firms to actually break the status quo.

7. Consumer Preferences for Environmental Welfare

The baseline model has predicted that agreements that break the status quo lead to higher prices paid by consumers. Can there nevertheless be a source of consumer welfare gain, when consumers have a preference for environmental welfare?

7.1 Within-Market Externality

If the consumers constitute a large portion of the overall population, one can argue that any reduction in environmental harm benefits the consumers within in the relevant market. The European Commission (2023) refers to this possibility as “collective benefits”. For the sake of contrast with section 6, let us consider a change of the model such that now the set of consumers coincides with the overall population. In this case, the OOM externalities which were discussed in the previous section do not actually happen out-of-market, but rather inside of the relevant market. The next Assumption 6 replaces Assumption 5.

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[24] For example, Article 101(3) TFEU requires that agreements are indispensable for attaining their objectives and that they may not eliminate competition further than necessary.

Assumption 6 (Within-market Externality).

a) Using the natural resource brings about a negative externality which is borne by the group of consumers in the relevant market. The "Within-Market" (WM) externality is constant per unit of usage and equals $e^{\mathrm{WM}} < 0$.
b) Even though reducing the usage of the natural resource benefits the group of consumers as a whole, no consumer is individually willing to contribute to such an effect.

Reducing the usage of the natural resource generates collective benefits for the group of consumers as a whole (Assumption 6a) but is subject to a free-rider problem (Assumption 6b). As a result, the demand system remains purely a function of the prices charged by the firms, and not their restriction levels. The condition for an agreement to break the status quo obtained in the benchmark model (presented in Proposition 1) continues to apply.

Proposition 5 (Welfare Effects When the Externality Happens Within-Market). A joint agreement that breaks the status quo is permissible for a competition authority that incorporates WM externalities in its objective function if and only if the WM externality per unit of usage of the natural resource (e^{WM}) is sufficiently negative.

Whereas Proposition 5 tells us that a horizontal agreement may be justified based on a within-market externality, the caveats which were discussed earlier (below Proposition 4) continue to apply.

7.2 Environmental Performance as a Way to Steal Customers from Rivals

What if better environmental performance enables a firm to attract customers that would otherwise have purchased from a competitor? The CMA guidelines (2023) note that "Where there is sufficient demand for a sustainable product to generate incentives for businesses to develop a sustainable product individually, an agreement involving cooperation between various parties will not be indispensable to achieving environmental sustainability benefits on the basis that consumers will in practice buy the product and businesses should compete to satisfy the demand." These guidelines are in line with the findings of Schinkel and Spiegel

(2017) who have shown that, when sustainability is a dimension of quality in the eyes of consumers, coordination of investments in sustainability is counterproductive. In this subsection, I will develop an extension to speak to this issue in the context of my model.

Consider the following demand function:

$$D\left(p_i, \overline{p}_{\mathrm{N}\setminus\{i\}}\right) + B\left(l_i, \overline{l}_{\mathrm{N}\setminus\{i\}}\right), \tag{19}$$

where the business-stealing effect associated with higher environmental performance is specified in a linear way such that

$$B\left(l_i, \overline{l}_{\mathrm{N}\setminus\{i\}}\right) = -bl_i + \frac{b}{n-1}\sum_{N\setminus\{i\}} l_j \tag{20}$$

and $\overline{l}_{\mathrm{N}\setminus\{i\}}$ is the vector of restriction levels other than l_i. Let the parameter b be positive. A unilateral increase of the restriction level reduces demand ($B_1 \leq 0$), whereas the demand faced by a firm increases as its competitors choose a higher restriction level ($B_2 \geq 0$).

It is assumed that demand is neutral with respect to a symmetric restriction level ($B_1 + B_2 = 0$). This property says that consumers only care about the environmental performance of a firm in comparison with that of other firms in the industry. A reduction of the symmetric level l by all firms in the industry does not expand the demand for the product. We can interpret such an assumption as reflecting that consumers may enjoy an increase in social status when purchasing from a firm that is *relatively* more environmentally friendly, compared with other firms in the industry.

Since demand is neutral with respect to a symmetric restriction level, the jointly optimal value for l^* is the same as in the benchmark model. However the presence of a business-stealing effect alters the status quo restriction level l^{SQ}. Let me denote the status quo restriction level in a general way as $l^{\mathrm{SQ}}(b)$ where $l^{\mathrm{SQ}}(0)$ corresponds to the benchmark model and $l^{\text{SQ}}(b)$ allows for the presence of a positive business-stealing parameter b. I will continue to assume that $l^{\text{SQ}}(b)$ is unique.

The first-order condition which characterizes $l^{\text{SQ}}(b)$ equals $\Pi_3 = 0$ and, by utilizing the demand function (19) and (20), can be rewritten as

$$\underbrace{-P(l)b}_{(-)} - C_2 = 0. \tag{21}$$

When $b > 0$, the first term in (21) is negative. The status quo level $l^{\text{SQ}}(b)$ is then characterized by $C_2 < 0$ (the natural resource is under-utilized from the perspective of minimizing costs). Firms depress their usage of the natural resource, below the cost-minimizing level, in an attempt to steal consumers from the rival firms.

We can thus see that firms already depress their usage of the natural resource even in the status quo (in the absence of a horizontal agreement). Does such an effect erode the ability of a horizontal agreement to reduce the usage of the natural resource below the usage level that prevails under the status quo? I will show that the answer to this question is yes.

Let $\hat{b}(l)$ represent the value of b that induces the restriction level l under the status quo (it is obtained by finding $P(l)$ and C_2 as a function of l and subsequently using the condition (21)). Recall that $l^{\text{SQ}}(b)$ is the unique restriction level resulting from a given value b. Since also $\hat{b}(l)$ is unique, the function $l^{\text{SQ}}(b)$ is strictly monotone.

For an agreement that breaks the status quo in the benchmark model ($l^* < l^{\text{SQ}}(0)$), it holds true that $P(l^*) > 0$ and $C_2|_{l=l^*} < 0$ (by Proposition 2b). Hence the value $\hat{b}$ that replicates l^* under the status quo is strictly positive. Figure 3 draws $l^{\text{SQ}}(b)$ using the property that it is strictly monotone.

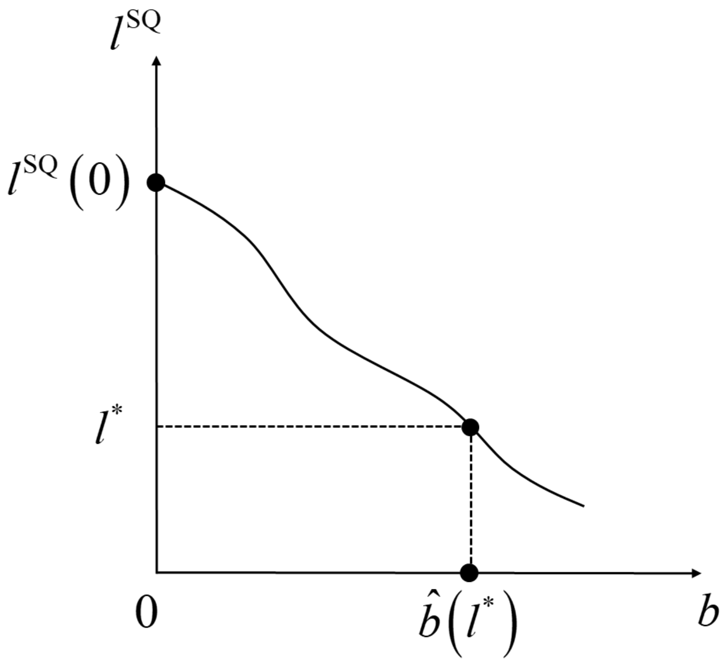

Figure 3: The effects of a business-stealing effect for an agreement type that breaks the status quo in the benchmark model .

Proposition 6 (Business-Stealing Effect). For an agreement type that breaks the status quo in the benchmark model, an effect whereby higher environmental performance attracts consumers that would otherwise have purchased from rivals reduces the restriction level under the status quo ($l^{\mathrm{SQ}}{}'(b) < 0$) without impacting the restriction level that firms jointly agree upon (l^*).

The agreement fails to break the status quo if and only if the business-stealing effect is sufficiently large ($b > \hat{b}(l^*)$). This result provides support for the CMA guidelines which state that an agreement may not be indispensable when there is sufficient demand for a sustainable product.

8. Concluding Remarks

An intense debate has been ongoing about the welfare standard that competition authorities should adopt for evaluating agreements between firms claiming to promote the green transition. However, it is of primary importance to understand whether a particular type of agreement is even able to deliver on its green promise. In this paper, I have considered a model where firms rely on two inputs for production: a natural resource and a basket of other resources, which are imperfect substitutes in the production process. Under baseline assumptions, a condition is obtained which reveals whether a particular type of horizontal agreement about the use of the natural resource actually breaks the status quo. The condition is applicable to a broad class of various types of restrictions that fall short of pure price fixing. Examples are collected in Table 2 which the reader can find in section 4 of this paper.

Agreements that break the status quo lead to a lower usage of the natural resource and higher prices paid by consumers. As such, there is a tradeoff between environmental and consumer welfare. My analysis has focused on types of agreements which may not discourage the usage of the basket of other resources. These types of agreements, conditional on breaking the status quo, achieve a bigger reduction in usage of the natural resource than a direct agreement between firms to raises prices by the same amount (which would fail the requirement that the usage of the basket of other resources may not be discouraged). Within the set of admissible agreements, I showed that firms select the type of agreement that requires as little substitution away from the natural resource as possible for a given increase in prices. In this respect, an agreement to restrict the absolute usage of the natural resource per firm tops the list from the perspective of the firms.

Even though there can be a welfare-based justification for permitting horizontal agreements about the use of the natural resource, my analysis highlights two caveats that must be considered. Most notably, the type of restriction chosen by the firms is the one achieving the least reduction in usage of the natural resource for a given price increase. Permitting a broader range of types of agreements—perhaps with the intention to foster the green transition—might therefore be counterproductive.[25] Secondly, in my model, firms nor consumers take the externality into account (reflecting the true nature of an externality). So both *the type* of restriction and *the level* associated with the restriction which are chosen by

[25] This type of result resembles that of Schinkel (2022) wherin a Robin Hood cartel only redistributes to the poor what is minimally required by the competition agency.

the firms are unconnected to the actual environmental externality associated with using the natural resource.

Competition authorities should be particularly skeptical towards joint agreements when consumers have a preference for purchasing from firms that perform better along the environmental dimension. In an extension, I have shown that the presence of such a preference erodes the ability of an agreement to break the status quo. Furthermore, whereas my model has not incorporated the risk of collusion, this too is an important factor that should be considered in a practical case. Here is it worth mentioning that a few empirical studies have found that collaboration between competitors on the dimension of R&D risks inducing collusion in the product market (Duso et al., 2014; Sovinsky, 2022). Sustainability agreements could be prone to a similar effect.

The government is the elephant in the room which has a responsibility in designing appropriate policies and regulations that take account of an environmental externality. Any government failure could for example arise due to an informational asymmetry between the industry and the government. As such, it would be interesting for future research to explore how asymmetric information could be introduced in the model. Perhaps asymmetric information could explain a different choice of type of restriction by firms than the one predicted by my analysis (a restriction of absolute usage of the natural resource).

If the government aims to design an environmental restriction instead of permitting the firms to do it themselves, then the results of my analysis can be used for predicting which types of restrictions are more likely to receive the support of industry federations. Certain quantitative restrictions may raise industry profits, as presented in Table 2. However a tax per unit of usage of the natural resource would not receive the support of the firms, even if the tax revenue is employed for an activity that benefits the whole industry.

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Appendix

Proof of Lemma 1

Lemma 1 is proven in a graphical way. Figure A1 depicts the isoquant $q_i = F(x_i, y_i)$ on a diagram which has x_i on the horizontal and y_i on the vertical axis. The isoquant is asymptotic to both axes by Assumption 2e. The "isolevel curve" $l_i = R(x_i, y_i)$ connects all the input combinations leading to the level l_i. Isolevel curves are delineated in Figure A1 using interrupted lines.

a) For a restriction of the absolute usage of the natural resource ($l_i = x_i$), the isolevel curve (depicted in Figure A1) is a vertical line and it intersects exactly once with the isoquant.
b) I will argue why a restriction of the usage of the natural resource relative to the production quantity ($l_i = x_i/q_i$) inherits the same property. Define $\tilde{l}_i = l_i q_i$ and notice that $\tilde{l}_i > 0$. The input combination which satisfies both $q_i = F(x_i, y_i)$ and $l_i = x_i/q_i$ is the same as the input combination which satisfies $q_i = F(x_i, y_i)$ and $\tilde{l}_i = x_i$. We know from a) that such an input combination exists and is unique.
c) A restriction of the usage of the natural resource relative to the usage of the basket of other resources determines the ratio $l_i = x_i/y_i$. It gives rise to an isolevel curve (depicted in Figure A1) which is linearly increasing from the origin. Hence, it intersects with the isoquant in a unique way
d) A restriction of the inverse usage of the basket of other resources ($l_i = 1/y_i$) leads to a horizontal isolevel curve (depicted in Figure A1) which also intersects once with the isoquant.
e) A restriction of $l_i = q_i/y_i$ inherits the same property. To see this, let us define $\tilde{l}_i = l_i/q_i$. We thus search for an input combination satisfying $q_i = F(x_i, y_i)$ and $\tilde{l}_i = 1/y_i$. It exists and is unique, as was shown in d).

f) Finally, a restriction of the inverse usage of the basket of other resources relative to the usage of natural resource determines the ratio $l_i = x_i / y_i$. Existence and uniqueness was shown in c).

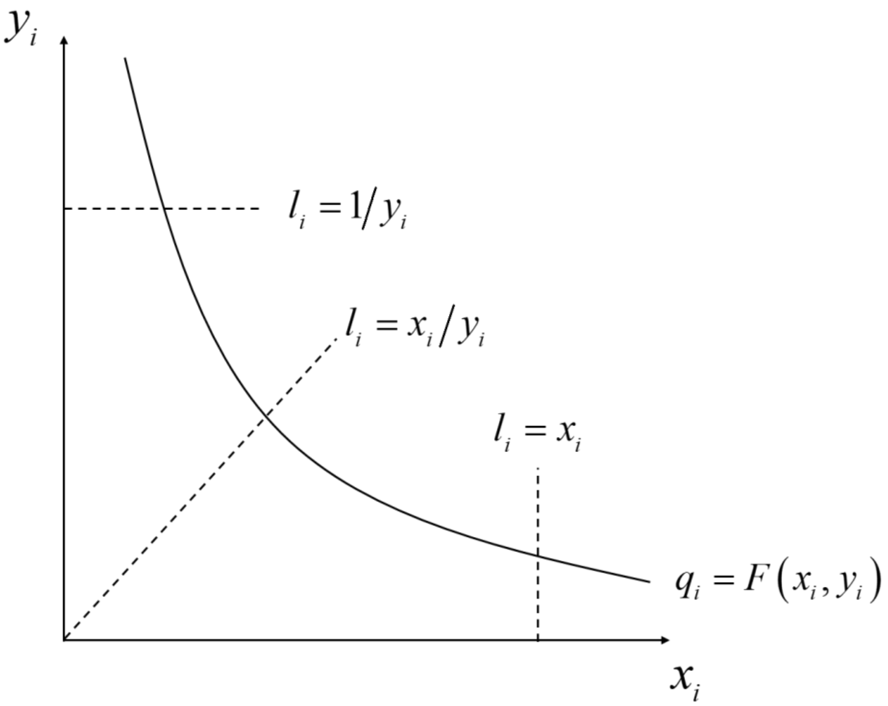

Figure A1: Existence of a unique combination of inputs (x_i, y_i) that yields any given production quantity q_i and level l_i, for the examples of restriction types presented in Table 1.

Proof of Proposition 1

The proof consists of four parts. I will omit the subscript i for brevity.

Part 1. Part 1 establishes auxiliary results. The properties of homogeneity in Assumptions 1 and 2 yield

$$\begin{cases} \rho l = R_1 x + R_2 y \\ \varphi q = F_1 x + F_2 y. \end{cases} \tag{A1}$$

Differentiating each of these two equations with respect to x and y, respectively, yields

$$\begin{cases} (\rho-1)R_1 = R_{11}x + R_{12}y \\ (\rho-1)R_2 = R_{12}x + R_{22}y \\ (\varphi-1)F_1 = F_{11}x + F_{12}y \\ (\varphi-1)F_2 = F_{12}x + F_{22}y, \end{cases} \tag{A2}$$

or equivalently

$$\begin{cases} R_{11} = (\rho-1)R_1x^{-1} - R_{12}x^{-1}y \\ R_{22} = (\rho-1)R_2y^{-1} - R_{12}xy^{-1} \\ F_{11} = (\varphi-1)F_1x^{-1} - F_{12}x^{-1}y \\ F_{22} = (\varphi-1)F_2y^{-1} - F_{12}xy^{-1}. \end{cases} \tag{A3}$$

Part 2. The production function $dq = F_1dx + F_2dy$ and the restriction $dl = R_1dx + R_2dy$ form a system of two equations which can be solved as follows:

$$\begin{cases} dx = G^{-1}(F_2dl - R_2dq) \\ dy = G^{-1}(R_1dq - F_1dl), \end{cases} \tag{A4}$$

where I define the function

$$G(x,y) \equiv F_2R_1 - F_1R_2 \tag{A5}$$

which satisfies $G > 0$. For a given level l (such that $dl = 0$), we can see from (A4) that a change in the production quantity affects the usage of the inputs as follows:

$$\begin{cases} X_1 = -G^{-1}R_2 \\ Y_1 = G^{-1}R_1. \end{cases} \tag{A6}$$

Expanding production happens by raising the use of both inputs, in such a way that the increasing effect of the extra usage of the natural resource on the level l is precisely offset by the effect on l of the extra usage of the basket of other resources.

For a given production quantity ($dq = 0$), a change dl affects the usage of inputs as follows:

$$\begin{cases} X_2 = G^{-1}F_2 \\ Y_2 = -G^{-1}F_1, \end{cases} \tag{A7}$$

A higher level associated with the restriction is associated with an increased usage of the natural resource and a lower usage of the basket of other resources.

Part 3. The cost of production is given by (6). The associated marginal cost of production, subject to l, can be written as $C_1 = p^x X_1 + p^y Y_1$. The effect of a change in the level l of the restriction on the marginal cost of production equals $C_{12} = p^x X_{12} + p^y Y_{12}$. The effect of a change in the level l on the way an extra unit of output is produced can be obtained, based on (A7), as

$$\begin{cases} X_{12} = G^{-1}\left(F_{12}X_1 + F_{22}Y_1\right) - G^{-2}\left(G_1X_1 + G_2Y_1\right)F_2 \\ Y_{12} = -G^{-1}\left(F_{11}X_1 + F_{12}Y_1\right) + G^{-2}\left(G_1X_1 + G_2Y_1\right)F_1. \end{cases} \tag{A8}$$

Employing (A6) yields

$$\begin{cases} X_{12} = G^{-2}\left(-F_{12}R_2 + F_{22}R_1\right) - G^{-3}\left(-G_1R_2 + G_2R_1\right)F_2 \\ Y_{12} = -G^{-2}\left(-F_{11}R_2 + F_{12}R_1\right) + G^{-3}\left(-G_1R_2 + G_2R_1\right)F_1, \end{cases} \tag{A9}$$

Employing (A9), the expression $C_{12} = p^x X_{12} + p^y Y_{12}$ can be written as

$$\begin{aligned} C_{12} &= p^xG^{-2}\left(-F_{12}R_2 + F_{22}R_1\right) - p^xG^{-3}\left(-G_1R_2 + G_2R_1\right)F_2 \\ &- p^yG^{-2}\left(-F_{11}R_2 + F_{12}R_1\right) + p^yG^{-3}\left(-G_1R_2 + G_2R_1\right)F_1. \end{aligned} \tag{A10}$$

We evaluate the expression when the necessary first-order condition for minimization of costs holds true (condition (15)). The condition equals $C_2 = p^x X_2 + p^y Y_2 = 0$ or equivalently (using (A7) and $G > 0$) $p^x F_2 - p^y F_1 = 0$ which can be written as $p^x = F_1F_2^{-1}p^y$. Substituting the expression in (A10) yields

$$\begin{aligned} C_{12} &= F_1F_2^{-1}p^yG^{-2}\left(-F_{12}R_2 + F_{22}R_1\right)\underline{-F_1F_2^{-1}p^yG^{-3}\left(-G_1R_2 + G_2R_1\right)F_2} \\ &- p^yG^{-2}\left(-F_{11}R_2 + F_{12}R_1\right)\underline{+p^yG^{-3}\left(-G_1R_2 + G_2R_1\right)F_1}. \end{aligned} \tag{A11}$$

Notice that the underscored terms cancel out. We can rearrange and obtain

$$C_{12} = p^y G^{-2}\left[\left(F_{11} - F_1 F_2^{-1} F_{12}\right) R_2 + \left(F_1 F_2^{-1} F_{22} - F_{12}\right) R_1\right]. \qquad \text{(A12)}$$

Using (A1) we can substitute $R_2 = y^{-1}\rho l - y^{-1} R_1 x$ to obtain

$$C_{12} = p^y G^{-2}\left[\begin{array}{l}\left(F_{11} - F_1 F_2^{-1} F_{12}\right) y^{-1}\rho l \\ +\underbrace{\left(-F_{11} x y^{-1} + F_1 F_2^{-1} F_{12} x y^{-1} + F_1 F_2^{-1} F_{22} - F_{12}\right)}_{\text{term A}} R_1\end{array}\right]. \qquad \text{(A13)}$$

I will show that term A equals zero. From (A3) we can substitute $F_{11} = (\varphi - 1) F_1 x^{-1} - F_{12} x^{-1} y$ in order to write term A as

$$\mathrm{A} = -(\varphi - 1) F_1 y^{-1} \underline{+F_{12}} + F_1 F_2^{-1} F_{12} x y^{-1} + F_1 F_2^{-1} F_{22} \underline{-F_{12}}\,. \qquad \text{(A14)}$$

Notice that the underscored terms cancel out. We can also use the last line in (A3) to see that $F_{12} x y^{-1} = (\varphi - 1) F_2 y^{-1} - F_{22}$ and hence (A14) can be written as

$$\mathrm{A} = -(\varphi - 1) F_1 y^{-1} + F_1 F_2^{-1} (\varphi - 1) F_2 y^{-1} - F_1 F_2^{-1} F_{22} + F_1 F_2^{-1} F_{22} = 0\,. \qquad \text{(A15)}$$

We can observe that term A indeed equals zero. Expression (A13) therefore simplifies as

$$C_{12} = p^y G^{-2}\left(F_{11} - F_1 F_2^{-1} F_{12}\right) y^{-1}\rho l\,. \qquad \text{(A16)}$$

Note that $p^y G^{-2} l > 0$. In order to conclude that the condition for effectiveness ($C_{12} < 0$) simplifies as $\rho l > 0$, it remains to show that

$$F_{11} - F_1 F_2^{-1} F_{12} < 0\,, \qquad \text{(A17)}$$

an objective which I pursue in Part 4.

Part 4. The part 4 of the proof draws initially from Osborne (2022). The production function is homogenous of degree φ which means, by definition, that $F(\lambda x, \lambda y) = \lambda^{\varphi} F(x, y)$. Taking the derivative of both sides of the equality with respect to x yields $\lambda F_1(\lambda x, \lambda y) = \lambda^{\varphi} F_1(x, y)$. Further dividing by λ gives us $F_1(\lambda x, \lambda y) = \lambda^{\varphi - 1} F_1(x, y)$. We can conclude that F_1 is homogenous of degree $\varphi - 1$. The same conclusion applies to F_2. Taken together, we can draw the conclusion that the slope of an isoquant ($-F_1/F_2$) is homogenous of degree zero. Figure A2 illustrates this property.

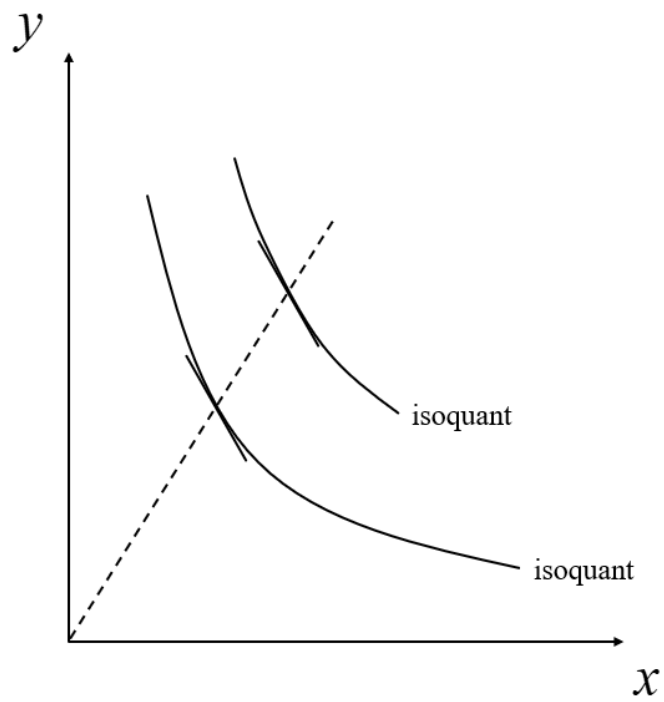

Figure A2: The slope of an isoquant is homogenous of degree zero.

A marginal increase in the usage of the natural resource, which preserves the original usage of the basket of other resources, leads to an input combination which is located on a ray through the origin that has a flatter slope. It raises the production quantity and leads to a flatter (less negative) slope of the isoquant. Mathematically, we can write that an increase in x raises the slope $-F_1 F_2^{-1}$ such that

$$\frac{d\left(-F_1 F_2^{-1}\right)}{dx} = -F_{11} F_2^{-1} + F_1 \left(F_2\right)^{-2} F_{12} > 0, \tag{A18}$$

which demonstrates that (A17) holds true.

Proof of Proposition 2

A marginal reduction of l below the value l^{SQ} raises marginal costs (as $C_{12}\big|_{l=l^{\mathrm{SQ}}} < 0$ by (18)) and hence raises the equilibrium price. I will argue that $C_{12}\big|_{l=l^*} < 0$ which means that the price continues to rise strictly as l shifts from l^{SQ} further down to l^*, by contradiction. Suppose not.

By continuity, there would exist a level $\hat{l}$ which fits within the interval $\hat{l} \in [l^*, l^{\mathrm{SQ}})$ satisfying $C_{12}\big|_{l=\hat{l}} = 0$. At this "tipping point" $\hat{l}$, the price-effect of a marginal change of the restriction level is zero. There is only a direct effect on cost ($\left.\frac{dC}{dl}\right|_{l=\hat{l}} = C_2\big|_{l=\hat{l}}$ and $\left.\frac{d\Pi}{dl}\right|_{l=\hat{l}} = -C_2\big|_{l=\hat{l}}$). I will argue that two observations hold true which contradict each other.

1. On the one hand, since $\hat{l}$ is lower than the status quo value l^{SQ}, the direct cost effect $C_2\big|_{l=\hat{l}}$ should be negative in light of strict convexity of the cost function (Assumption 4b).

2. On the other hand, strict concavity of the profit function (Assumption 4c) would require the direct cost effect $C_2\big|_{l=\hat{l}}$ to be positive, in light of the fact that $\hat{l}$ exceeds the jointly optimal value l^*.

We conclude that $C_{12}\big|_{l\in[l^*,l^{\mathrm{SQ}}]} < 0$ holds true over the entire interval $l \in [l^*, l^{\mathrm{SQ}}]$ and that the agreement raises the equilibrium price, which demonstrates Proposition 2a.

Finally, to demonstrate part b of Proposition 2, let us focus on the optimality condition for l^* which is obtained by equating (13) to zero. We know from the arguments presented previously that $C_{12}\big|_{l=l^*} < 0$. Consequently, the optimality condition for l^* requires that $C_2\big|_{l=l^*} < 0$. More specifically it means that $\left(p^x X_2 + p^y Y_2\right)\big|_{l=l^*} < 0$ or equivalently (using (A7)) that $\left(p^x F_2 - p^y F_1\right)\big|_{l=l^*} < 0$.

Proof of Proposition 3

Part 1. The subscript i is omitted for brevity. Price-equivalence requires marginal costs to be identical such that

$$\underbrace{p^x X_1^C + p^y Y_1^C}_{\text{marginal cost under restriction C}} = \underbrace{p^x X_1^D + p^y Y_1^D}_{\text{marginal cost under restriction D}} \tag{A19}$$

or equivalently (using (A5) and (A6))

$$\underbrace{\frac{-p^x R_2^C + p^y R_1^C}{R_1^C F_2^C - R_2^C F_1^C}}_{\text{marginal cost under restriction C}} = \underbrace{\frac{-p^x R_2^D + p^y R_1^D}{R_1^D F_2^D - R_2^D F_1^D}}_{\text{marginal cost under restriction D}} . \tag{A20}$$

Restriction of type C is a restriction of the absolute usage of the natural resource. Substituting $R_2^C = 0$ (the restriction level is independent of the usage of the basket of other resources) into (A20) makes it possible to state:

$$\underbrace{\frac{p^y}{F_2^C}}_{\substack{\text{marginal cost under}\\ \text{restriction C}}} = \underbrace{\frac{-p^x R_2^D + p^y R_1^D}{R_1^D F_2^D - R_2^D F_1^D}}_{\text{marginal cost under restriction D}} . \tag{A21}$$

Part 2. Let us define the following measure of substitution away from the natural resource under the joint agreement of type D:

$$S \equiv \frac{F_1^D}{F_2^D} - \frac{p^x}{p^y} . \tag{A22}$$

The measure S reflects the difference between the (negative) slope of the isoquant and the (negative) slope of the isocost line. Since the agreement of type D breaks the status quo, it holds true (by Proposition 2b) that $S > 0$. We can write

$$p^x = \frac{F_1^D}{F_2^D} p^y - S p^y . \tag{A23}$$

Substituting the expression for p^x given in (A23), we can simplify (A21) as

$$\frac{p^y}{F_2^C} = \frac{-\left(\frac{F_1^D}{F_2^D} p^y - Sp^y\right) R_2^D + p^y R_1^D}{R_1^D F_2^D - R_2^D F_1^D} \qquad \text{(A24)}$$

or

$$\frac{p^y}{F_2^C} = \frac{R_1^D F_2^D - R_2^D F_1^D + F_2^D R_2^D S}{R_1^D F_2^D - R_2^D F_1^D} \frac{p^y}{F_2^D} \qquad \text{(A25)}$$

which is equivalent to

$$\frac{p^y}{F_2^C} = \frac{p^y}{F_2^D} + \underbrace{\frac{F_2^D R_2^D S}{R_1^D F_2^D - R_2^D F_1^D} \frac{p^y}{F_2^D}}_{(-)}. \qquad \text{(A26)}$$

Notice that the last term in (A26) is negative because $R_2^D < 0$ and $S > 0$. Hence, we conclude that

$$F_2^C > F_2^D. \qquad \text{(A27)}$$

Part 3. Finally, we show that $F_2^C > F_2^D$ means that under restriction C firms rely less on the natural resource than under the restriction of type D. Recall that the production quantity is identical for both restriction types (as they are price-equivalent by construction). The effect on F_2 is in general characterized as

$$dF_2 = F_{12}dx + F_{22}dy. \qquad \text{(A28)}$$

A movement along an isoquant satisfies $F_1 dx + F_2 dy = 0$ and hence $dy = -F_1 F_2^{-1} dx$. This means that any reduction in usage of the natural resource (negative dx) is accompanied by an increased usage of the basket of other resources (positive dy) such that the quantity produced is unchanged. The effect on F_2 of a movement along the isoquant equals

$$dF_2 = dx\underbrace{\left(F_{12} - F_{22}F_1F_2^{-1}\right)}_{(+)} \qquad \text{(A29)}$$

We showed earlier (in (A17) and (A18)) that the last term in (A29) is positive. We conclude that the lower value for F_2 under the restriction of type C compared with restriction D (see (A27)) must be explained by a lower usage of the natural resource.