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Abstract

Corporations make significant direct contributions to environmental improvement and also indirect contributions, through expenditure on process and product innovation. Environmental protection is a public good and so may be under-supplied in a competitive environment. European law requires competition authorities to consider public interest arguments. The public interest defence for allowing a cartel to operate is based on the argument that the additional profitability induces cartel members to make greater environmental contributions that more than offset the welfare loss due to non-competitive pricing. We explore profit-seeking motivations for the corporate environmental expenditures, leaving aside corporate social responsibility concerns. Two motives are considered: environmental improvement leading to reduced production costs, and publicized environmental expenditures boosting brand image. Allowing the operational firms to form a cartel and raise prices above Nash equilibrium levels always reduces environmental quality and consumer welfare. As a consequence, we find no support for the public interest defence.

1 Introduction

There is frequent media attention placed upon damage to the environment caused by the activities of firms. The Deepwater Horizon oil spill in April 2010 is an extreme case, but there are many others including the ongoing debate about the potential harm caused by fracking to extract shale gas. What receives much less attention are the resources spent by firms on improving the environment. Morgenstern *et al.* (2001) cite a US EPA estimate that these expenditures amount to 2 percent of GDP.[1] Vernon (2000) reports that the corporate sector in Australia contributed about 40 per cent of total environmental expenditure. Corporations also contribute indirectly to environmental improvement through improvement of processes and products. For example, between 1980 and 2014 the average mileage per gallon of cars and small trucks in the US has increased from 14.9 to

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[1] See US Environmental Protection Agency (1990).

21.14.[2] In 2014 Toyota issued green bonds for 1.75 billion US dollars, to finance new gas-electric and other alternative fuel car production. Apple's $1.5 billion green bond issuance, announced in 2016, is intended to fund the company's conversion to renewable energy and use of biodegradable materials, and projects to improve the energy-efficiency of heating and cooling systems.[3]

The observation that firms contribute to environment improvement has led the Netherlands to explicitly allow the "public interest" argument of sustainability to enter a cartel defence. This defence is founded on the profitability of the cartel allowing the firms involved to make socially-useful expenditures (such as the support of environmental projects) that would not be possible if the cartel were dismantled. The defence is accepted if the social benefits of the expenditures can be demonstrated to exceed the losses through reduced competition and the cartel is permitted. The extent to which national competition authorities should follow the Netherlands and take account of non-competition interests is under debate in the EU. The European Commission itself holds the view that competition authorities should consider only arguments directly concerning competition. A counter-argument is that the position of the Commission is inconsistent with EU Treaties and case law of the European courts. The basis of this argument is that the Treaty on the Functioning of the European Union imposes a duty on the European Commission and the competition authorities to consider public interest arguments.

The Dutch competition authority (ACM) is at the forefront of arguing for the integration of the public interest argument of sustainability in cartel cases. A position paper (ACM, 2013) states that ACM will accept the argument of collusive production of public interests as a defence. The criteria include the contribution of cartel's activities to "*improving the production or distribution of goods or to promoting technical or economic progress, while allowing consumers a fair share of the resulting benefit.*" The logic of the argument is that the public interest – such as environmental protection – may not be supplied in a competitive environment. A cartel agreement to restrict the supply of a good can provide the coordination that is needed to supply the public interest.

These observations raise two questions: first, why corporations make environmental contributions of such significance, and, second, can the consequences of the contributions justify the public interest defence of a cartel.

A simple answer to the first question might be that environmental expenditures are an act of pure goodwill on the part of the corporations driven by a sense of corporate social responsibility. This interpretation is incomplete because any corporate environmental expenditure needs explicit approval of the company's managers and therefore must be a deliberate act with perceived benefits for the corporation. To explain why contributions are made we must go beyond altruism to search for motives that are founded upon material benefit. Our starting point is that profit maximization is a company's legal obligation to shareholders. Therefore, we seek to explain environmental contributions as the outcome of profit maximization, without having to resort to invoking business ethics or corporate social responsibility. To address the second question we analyze the effect of cartelization on environmental quality and social welfare. In particular, we explore whether there are circumstances in which the formation of a cartel can increase public welfare because of its impact on the provision of environmental expenditures.

We consider two potential motives for corporations environmental expenditures that have differing economic effects, and construct a model that combines both motives.

The first motive is based on expenditures causing a direct reduction in production costs for all

[2] http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_04_23.html

[3] Data on labelled green bonds are tracked by Climate Bonds Initiative, a UK charity. See https://www.climatebonds.net/cbi/pub/data/bonds.

active firms. What we have in mind here is that the mitigation of environmental damage will feed back into lower costs, so there is a supply-side argument for environmental expenditures.[4] The assumption that environmental damage reduces the level of output is frequently invoked by integrated assessment models (IAMs) that are used to evaluate the impact of greenhouse gas emissions on the economy. These models are familiar from the review of Stern (2007) and much other research on climate damage such as the DICE model (Nordhaus, 2008) and the REMIND model (Luderer *et al.*, 2013). What the IAM modelling has generally failed to do (partly because it is undertaken at a macro level) is to observe that corporations have an incentive to undertake acts to mitigate the damage. The interesting economic feature is that mitigation is a public good so that the benefit is shared among firms. This makes the incentive to contribute greater when the number of firms is smaller, and provides the interesting trade-off between the level of competition and efficiency in mitigation that we explore in this paper.

The second motive is driven by demand-side considerations and is based on the assumption that publicized environmental activities boost brand image. The many adverts that extol the environment-saving efforts of corporations demonstrate the role of brand image as a key factor in driving sales. Consequently, brand image is carefully cultivated by many corporations. It is hard to overstate the potential benefits for a corporation that is able to embed environmentalism within its brand. An Ipsos MORI poll reported in TANDBERG (2007) discovered that "*More than half of global consumers interviewed said they would prefer to purchase products and services from a company with a good environmental reputation, and almost 80% of global workers believe that working for an environmentally ethical organization is important. That amounts to one billion consumers and over 700 million workers worldwide.*" A YouGov (2016) survey of millenials carried out for GT Nexus supply chain management platform found that 22 per cent of respondents would switch brand if products were not environmentally friendly. Reinhardt (2008) argues that a firm aiming to develop an environmental image "*must discover or create a willingness in consumers to pay for public goods; they must overcome barriers to the dissemination of credible information about the environmental attributes of their products; and they must defend themselves against imitation.*" This captures the fundamental problem for a firm: development of a brand image is costly and can reduce profitability unless it creates a sufficient increase in demand.

In a framework where environmental contributions affect profits both on the supply side, by changing production cost, and on the demand side, by satisfying consumer preferences, we analyze the equilibrium that emerges and the validity of the public interest defence. The public interest defence argument concerns the consequences of giving a fixed number of firms the right to act as a cartel with additional marker power. We can show that an increase in cartel power will always *reduce* environmental quality and will lead to a *lower* level of consumer welfare. No case is found in which the public interest defence can be sustained.

This conclusion should be contrasted to that of Schinkel and Spiegel (2017) who show, in a duopoly model with linear demand, that the validity of the public interest defence depends on the order of moves in the strategic game between firms. In their model, each firm chooses output and the sustainability attribute of its product. The order in which these are chosen determines whether the chosen sustainability attribute is higher or lower with a cartel. Our analysis is more general in three separate aspects. First, we allow any number of firms to be active and give considerable attention to how the number of firms affects welfare. Second, we adopt a preference system that permits the elasticity of demand to be parametrically varied. Third, and most importantly, we

[4] This should be distinguished from the assumption that a reduction in output reduces the emission of harmful by-products (see, e.g. André et al., 2009, Maloney and McCormick, 1982).

consider three different forms of environmental expenditures. The first two of the three seek to meet consumer preferences and are thus two different forms of expenditure on brand image. One is "nominal" expenditure – such as advertising – that promotes image without substantive change to the product. The other – "real" expenditure – improves the product as well as image and is similar to the sustainability attribute of Schinkel and Spiegel (2017). The third form of environmental expenditure is a form of mitigation that reduces production cost and has the characteristics of a public good for the firms. This introduces entirely new issues into the analysis and an additional set of strategic considerations.

Our paper contributes to the literature on corporate environmentalism and the voluntary approach to environmental protection (Khanna, 2001, Lyon and Maxwell, 2004, Segerson 2013). While much of this literature assumes that producers maximize a combination of profits and consumer welfare, reflecting the assumption of corporate social responsibility, we explore pure profit-seeking motives for green behaviour, with a specific focus on the interaction between competition regulation and voluntary environmental contributions, abstracting from the impact of mandatory environmental programmes and policies. The novelty of our work is the use of a theoretical framework that allows for the analysis of strategic behavior in a market with an arbitrary degree of market power, and the simultaneous effect of voluntary environmental contributions on the supply and demand sides of the market. This general approach reveals potential non-monotonicity in the effect of corporate environmentalism on social welfare, and addresses the viability of an important policy measure debated by European policy-makers.

The rest of the paper is structured as the following. Section 2 presents an overview of the Dixit-Stiglitz (1977) model of monopolistic competition, and its generalizations, which serves as the basic framework for our analysis. Section 3 formalizes the motives for environmental expenditures. The consequences of increased competition upon environmental expenditures are studied in section 4. Section 5 employs the model to address the issue of public interest and cartel formation. Conclusions are given in Section 6. All proofs are in the Appendix.

2 Consumer Preferences with Brand Image

We build our analysis on an extension of the Dixit-Stiglitz (1977) model of monopolistic competition. d'Aspremont *et al.* (1996) distinguish among three versions of the Dixit-Stiglitz model, according to the assumption under which the demand elasticities are calculated. In the first version, as developed in the original paper of Dixit and Stiglitz (1977), it is assumed that the firms ignore the effect of their pricing decisions on the aggregate price index. This assumption is most plausible when the number of firms is "large". The second version, due to Yang and Heijdra (1993), takes into account the price index effect, but ignores the indirect income-feedback effect. Finally, the third version, developed by d'Aspremont *et al.* (1996), considers the effect of pricing decisions on consumer income, which is referred to as the Ford effect, in a model where the numeraire good is interpreted as leisure (the firms employ the consumers as workers).

We choose to model the environmental contributions of firms in the Yang and Heijdra version of the Dixit-Stiglitz model, ignoring the Ford effect. This is because we wish to consider cases with a small number of firms which makes the price-index effect important. However, we view the industry as a small part of a larger world, so feel it is safe to set aside the income-feedback effect. This partial equilibrium approach focusses on the production of an imperfectly competitive polluting industry, on the interaction between competition and contributions to environmental improvement, and on the welfare implications. The choice of the second version is supported by assuming that the utility function of the representative consumer is separable in the goods produced by the industry under analysis and all other goods, and that the expenditure on the former is fixed.

The three versions of the model can be distinguished as follows. Denote the number of active firms by N and consumption of their outputs by $\{q_1, \ldots, q_N\}$. It is assumed that the goods are substitutes and that utility has the CES form, so

$$U(q_1, \ldots, q_N) = \left[\sum_{j=1}^{N} q_j^{(\sigma-1)/\sigma}\right]^{\sigma/(\sigma-1)}, \tag{1}$$

with $\sigma > 1$. It is also assumed that expenditure, $I \equiv \sum_{j=1}^{n} p_j q_j$, on these goods is fixed, where p_j denotes the price of good j.[5] The demand function that results from maximization of utility in (1) is given by

$$q_j = \frac{I}{NP}\left(\frac{p_j}{P}\right)^{-\sigma}, \tag{2}$$

where the price index, P, is defined by[6]

$$P = \left(\frac{1}{N}\sum_{j=1}^{N} p_j^{1-\sigma}\right)^{1/(1-\sigma)}. \tag{3}$$

The elasticity of the price index with respect to the price of good j is

$$\varepsilon_{Pj} \equiv \frac{p_j}{P}\frac{\partial P}{\partial p_j} = \frac{1}{N}\left[\frac{P}{p_j}\right]^{\sigma-1}.$$

Clearly, $\lim_{N\to\infty} \varepsilon_{Pj} = 0$, and in the symmetric equilibrium ($p_j = P$ for all j) $\varepsilon_{Pj} = 1/N$. Note that firm j's market share is

$$s_j \equiv \frac{p_j q_j}{I} = \frac{p_j}{I}\frac{I}{NP}\left(\frac{p_j}{P}\right)^{-\sigma} = \frac{1}{N}\left[\frac{P}{p_j}\right]^{\sigma-1} = \varepsilon_{Pj},$$

which gives another interpretation of the elasticity of the price index.

The Dixit-Stiglitz version of the model assumes $\varepsilon_{Pj} = 0$, leading to the the elasticity of demand

$$\varepsilon_j^{DS} \equiv -\frac{p_j}{q_j}\left.\frac{\partial q_j}{\partial p_j}\right|_P = \sigma, \tag{4}$$

so the demand for product j becomes more elastic for given prices as σ increases. In the Yang-Heijdra version adopted in this paper the elasticity of demand contains an additional term due to the price index effect:

$$\begin{aligned}
\varepsilon_j^{YH} &\equiv -\frac{p_j}{q_j}\left.\frac{\partial q_j}{\partial p_j}\right|_I = -\frac{p_j}{q_j}\left[\left.\frac{\partial q_j}{\partial p_j}\right|_P + \left.\frac{\partial q_j}{\partial P}\right|_{p_j}\frac{\partial P}{\partial p_j}\right] \\
&= \sigma - \frac{P}{q_j}\left.\frac{\partial q_j}{\partial P}\right|_{p_j} \times \frac{p_j}{q_j}\frac{\partial P}{\partial p_j} = \sigma - (\sigma-1)\,\varepsilon_{Pj} \\
&= \sigma - (\sigma-1)\,s_j.
\end{aligned} \tag{5}$$

[5] This, for example, would be implied by a Cobb-Douglas utility, $u(q_0, q_1, \ldots, q_N) = q_0^{1-\alpha}\left[U(q_1, \ldots, q_N)\right]^{\alpha}$ where q_0 is the numeraire good.

[6] The associated quantity index is $Q = \left(\frac{1}{N}\sum_{j=1}^{N} q_j^{(\sigma-1)/\sigma}\right)^{\sigma/(\sigma-1)}$, so that $I = NPQ$.

The Yang-Heijdra version is equivalent to assuming strategic price-setting behavior of the firms, whereby each firm takes into account how its pricing decision affects the aggregate price index and, thus, the prices set by other firms. In a symmetric equilibrium, where $s_j = \frac{1}{N}$ all j,

$$\varepsilon^{YH}(N) \equiv \sigma - \frac{\sigma - 1}{N}. \tag{6}$$

It can be seen directly that in the monopoly case $\varepsilon_j^{YH} = 1$ since the fixed expenditure implies $q = I/p$. The profit-maximization problem in this case is not well-defined, so in the analysis we assume that $N \geq 2$.[7] One can see that the elasticity increases with N. Although N is integer, for the purpose of the comparative statics analysis we will treat N as a continuous variable and $\varepsilon^{YH}(N)$ as a differentiable function, with

$$\frac{d\varepsilon^{YH}}{dN} = \frac{\sigma - 1}{N^2} > 0.$$

For the purpose of our analysis we extend the Yang and Heijdra model to include brand image: we imagine consumers to care about the environmental quality of the products they consume. The concern can be related to real environmental attributes, such as beauty products not being tested on animals or food products that are grown organically,[8] or equally it can depend only on the cultivated brand image of the product with an absence of any real underlying environmental benefit. We assume that consumers do not distinguish between the “real” and the “nominal” components of the environmental brand image and perceive only an “aggregate” environmental quality.[9] Specifically, we assume that the quantity of consumption of good j, q_j, and the perceived environmental brand image, or quality, z_j, enter multiplicatively into a generalization of (1)

$$U(q, z) = \left[\sum_{j=1}^{N} (q_j z_j)^{(\sigma-1)/\sigma}\right]^{\sigma/(\sigma-1)}. \tag{7}$$

The demand function that results from the maximization of utility is given by

$$q_j z_j = \frac{I}{NP_Z}\left(\frac{p_j/z_j}{P_Z}\right)^{-\sigma}, \tag{8}$$

where the quality-adjusted price index for the N products is[10]

$$P_Z = \left(\frac{1}{N}\sum_{j=1}^{n}\left(\frac{p_j}{z_j}\right)^{1-\sigma}\right)^{1/(1-\sigma)}. \tag{9}$$

The elasticity of demand is then obtained by applying the definition in (5).

[7] Relaxing the fixed expenditure assumption to allow monopoly to be incorporated would considerably complicate the analysis. As will become clear, it would not add anything of substance to our very definite final conclusion.

[8] Another application is fair trade. A fair-trade label appeals to particular groups of consumers and so raises demand. At the same time, inputs acquired from fair-trade sources typically result in extra costs for producers. Arguably, support of fair trade may contribute to the protection of environment (say, local small-scale farms might be likely to use “greener”, albeit less efficient technologies).

[9] The model has some similarities to that of Sengupta (2015). In the Sengupta model consumers do not observe whether firms invest in green technology or not but try to make an inference from price. In our model all consumers observe z and accept the observation as a sign of environmental quality.

[10] The corresponding quantity index adjusted for environmental quality is $Q_Z = \left[\frac{1}{N}\sum_{j=1}^{N}(z_j q_j)^{(\sigma-1)/\sigma}\right]^{\sigma/(\sigma-1)}$.

3 Environmental Expenditures

The total environmental expenditures by firms consist of brand image expenditures affecting product demand and the cost reduction expenditures affecting supply. Brand image is determined by a combination of expenditure on *nominal* environmental quality improvement and expenditure on *real* quality improvement. By nominal quality improvement we have in mind expenditure on promotion of environmental brand image without any activity beneficial for the environment taking place. In contrast, real quality improvement is brought about by actual environmental activity so it enhances environmental quality. Nominal and real quality are aggregated into the environmental brand image as perceived by consumers. The cost-reducing form of environmental expenditure causes a *direct* improvement in the quality of the environment but is not included in the perception of product quality by consumers.

Formally, let E_j denote the environmental expenditures by firm j. Amount E_j^1 is allocated to nominal quality improvement, E_j^2 to real quality improvement, and E_j^3 to direct expenditure on environmental improvement. By definition, $E_j^1 + E_j^2 + E_j^3 = E_j$.

Our first perspective on environmental expenditures is to model their role in the improvement of brand image which affects consumer demand. The frequent portrayal in advertising of the positive environmental pedigree of products is abundant evidence that an environmental brand image is very profitable. Brand image can be boosted by changes in technology or in product attributes to make them environmentally friendly, or by persuasive advertising, without substantial changes. Consumer preferences are determined by the quantity and quality of the N goods as described in (7). The perceived brand image of good j is determined by a combination of the nominal and the real environmental qualities. The aggregation of the two expenditures into an overall level of quality, z_j, is determined by the CES function

$$z_j = \left[(1-\xi)\left(z_j^1\right)^{\alpha} + \xi\left(z_j^2\right)^{\alpha}\right]^{1/\alpha}, \ \alpha > 0, \ \xi \in [0,1]. \tag{10}$$

The relationship between the quality levels, $\left\{z_j^1, z_j^2\right\}$, and the allocation of environmental expenditure $\left\{E_j^1, E_j^2\right\}$ for firm j are given by cost functions $\left\{C_1\left(z_j^1\right), C_2\left(z_j^2\right)\right\}$:

$$E_j^1 = C_1\left(z_j^1\right), \ E_j^2 = C_2\left(z_j^2\right). \tag{11}$$

Our second perspective on the environmental expenditures by firms is their effect on the production cost. Atmospheric greenhouse gas accumulation is modelled in Stern (2007), and many other IAMs, as a public bad that reduces the aggregate level of output. The incentives for firms to mitigate the damage are rarely explored, nor can IAMs built on an aggregate production function model what happens at the individual firm level. We model the impact of environment on firms by assuming that a reduction in environmental quality increases each firm's cost of production and, hence, will reduce the profit-maximizing output level if all else is constant. We also assume that firms can mitigate this effect by making contributions to environmental improvement. Pollution abatement activities can directly reduce the production cost for the firms if, for example, they allow recycling of some inputs (such as water), or reduce health damage for the labor force that otherwise would lead to lower productivity. This structure allows us to model the impact of environmental quality on production and the resulting mitigation activities of firms.

The link between environment and production cost causes the firms to be linked strategically in two dimensions. The first dimension is the standard form of price competition on the final product market. The second dimension is through the impact of environmental contributions on production costs. Environmental improvement is a public good because it reduces the production cost of all firms. so the considerations of free-riding apply (Cornes and Sandler, 1996). These features combine to make it socially beneficial to restrict competition in some cases.

Let e denote the level of environmental quality that is common for all firms, and let $c_j(e)$ be the marginal cost of production of firm j when environment quality is at level e. The profit of firm j with total environmental expenditure E_j is

$$\pi_j = [p_j - c(e)] q_j - E_j.$$

An improvement in environmental quality reduces the production cost for all firms, so that $c_j'(e) < 0$. We assume that the marginal cost of production of good j is independent of z_j, the environmental brand image perceived by the consumers.

The level of environmental quality is determined by aggregating real and direct expenditures as

$$e = (1-\eta)\sum_{i=1}^{N} E_i^2 + \eta \sum_{i=1}^{N} E_i^3, \tag{12}$$

so that the effect of expenditure on quality is proportional to spending, but the rate of proportionality is different for the two types of expenditure. Eliminating E_i^3,

$$e = \eta \sum_{i=1}^{N} E_i - (2\eta - 1)\sum_{i=1}^{N} E_i^1 - \eta \sum_{i=1}^{N} E_i^2. \tag{13}$$

We are interested in an interior equilibrium, where a strictly positive amount is allocated to each type of expenditure. Therefore, we must assume $\frac{1}{2} < \eta < 1$; otherwise expenditure on real quality improvement will strictly dominate direct expenditure, so no direct expenditure would occur.

4 Consequences of Competition

In the absence of environmental considerations an increase in competition - by which we mean a greater number of active firms - is always beneficial for welfare. The consumer gains from both increased variety and a lower equilibrium price, and the gains more than offset the loss in aggregate profit. The outcome is not so clear when firms make environmental expenditures. Expenditures on brand image are a form of non-price competition but improve the product from the consumer's perspective and some part also improve environmental quality. Expenditures on mitigation reduce production cost but are a public good so that the number of firms changes the strategic incentive to contribute. These observations justify a careful investigation of how the equilibrium is affected by an increase in competition.

The first result determines the necessary conditions of firm j for the choice of price and the allocation of environmental expenditure. These equilibrium conditions form the basis of the comparative statics analysis that follows.

Lemma 1 *The profit-maximizing choices of firm j are described by the necessary conditions:*

$$
\begin{aligned}
p_j &= c(e)\frac{\varepsilon_j^{YH}}{\varepsilon_j^{YH}-1}, && (14)\\
z_j^1 C_1'\left(z_j^1\right) &= I\frac{s_j(1-s_j)(\sigma-1)}{\varepsilon_j^{YH}}(1-\xi)\left[\frac{z_j^1}{z_j}\right]^{\alpha}, && (15)\\
\frac{C_1'\left(z_j^1\right)}{C_2'\left(z_j^2\right)} &= \frac{2\eta-1}{\eta}\frac{1-\xi}{\xi}\left[\frac{z_j^1}{z_j^2}\right]^{\alpha-1}, && (16)\\
-\eta c'(e)\,q_j-1 &= 0. && (17)
\end{aligned}
$$

The first condition (14) captures the mark-up of price over marginal cost. Condition (15) relates the marginal cost of nominal quality to the marginal benefit improvement. The third condition, (16), balances the allocation of expenditure between the two forms of brand image on the basis of effectiveness and the ratio of marginal costs. The fourth, (17), equates the marginal benefit of an incremental environmental improvement to the marginal cost.

For analytical tractability we now assume that the cost functions are isoelastic

$$
\begin{aligned}
c(e) &= \beta e^{-\gamma},\ \beta>0,\ \gamma>0; && (18)\\
C_k\left(z_j^k\right) &= \frac{\left(z_j^k\right)^{\mu}}{\theta_k},\ \theta_k>0,\ \mu\geq 1;\ k=1,2. && (19)
\end{aligned}
$$

Using these functional forms it is possible to determine the allocation of environmental expenditure between nominal and real quality improvement and the equilibrium quality of the environment.

The second result determines the division of environmental expenditures of each firm, j, as a function of equilibrium market share.

Lemma 2 *The allocation of expenditure on nominal and real quality improvement is determined by:*

$$
\begin{aligned}
E_j^1 &= \frac{1-\xi}{\omega}\frac{s_jI}{\mu}\left[1-\frac{1}{\varepsilon_j^{YH}}\right], && (20)\\
E_j^2 &= \left[\frac{1-\xi}{\xi}\frac{2\eta-1}{\eta}\right]^{\mu/(\alpha-\mu)}\left[\frac{\theta_1}{\theta_2}\right]^{\alpha/(\alpha-\mu)}E_j^1, && (21)
\end{aligned}
$$

where $\omega=1-\xi+\xi\left[\frac{1-\xi}{\xi}\frac{\theta_1}{\theta_2}\frac{2\eta-1}{\eta}\right]^{\alpha/(\alpha-\mu)}$.

When the equilibrium is symmetric between firms the results in lemma 2 can be employed to find an explicit solution for the equilibrium environmental contribution of each firm and the equilibrium environmental quality.

Lemma 3 *The total environmental expenditure by each firm is*

$$
E^*=\frac{I}{N}\left[\frac{\gamma}{N}+\frac{1}{\mu}\right]\frac{\varepsilon^{YH}-1}{\varepsilon^{YH}}, \quad (22)
$$

and aggregate environmental quality is

$$e^{*}=\frac{\gamma\eta I}{N}\frac{\varepsilon^{YH}-1}{\varepsilon^{YH}}. \tag{23}$$

Note that the aggregate environmental quality is not simply a multiple of the environmental expenditures by individual firms. This is due to the fact that the nominal environmental expenditures do not contribute to the quality of the environment. The price in the symmetric equilibrium is given by

$$p^{*}=\beta\left[\frac{N}{\gamma\eta I}\right]^{\gamma}\left[\frac{\varepsilon^{YH}}{\varepsilon^{YH}-1}\right]^{1+\gamma} \tag{24}$$

The next proposition describes the impact of an increase in the number of firms on environmental quality.[11]

Proposition 1 *An increase in the number of firms reduces aggregate environmental quality and increases the production cost of each firm.*

The proposition shows that in this model, the free-rider effect is so strong that a reduction in competition actually increases real contributions towards improvement of environmental quality. This result holds when there are two or more active firms, so we can conclude that environmental quality is highest when there is monopoly and the free-rider effect is eliminated. This is in sharp contrast to the private provision of a public good by households for which there is no clear effect of numbers on provision (see Myles, 1995). The result shows that competition will not be good for the environment when the private sector is relied upon to finance environmental improvements.

Next, we look at the effect of competition on profits. The profit level of an individual firm in a symmetric equilibrium are given by

$$\pi^{*}=\frac{I}{N\varepsilon^{YH}}\left[1-\left(\frac{\gamma}{N}+\frac{1}{\mu}\right)\left(\varepsilon^{YH}-1\right)\right], \tag{25}$$

and aggregate profit is

$$\Pi^{*}=N\pi^{*}. \tag{26}$$

Profit will be non-negative in equilibrium if $\frac{\gamma}{N}+\frac{1}{\mu}\leq\frac{1}{\varepsilon^{YH}-1}$, which can be rewritten as

$$\sigma-1\leq\mu\frac{N^{2}}{(N-1)(N+\gamma\mu)}. \tag{27}$$

In what follows we focus on symmetric equilibria where (27) holds.

It is easy to show that for sufficiently large N the profit of an individual firm falls as N increases. For large N the non-negativity condition (27) can be rewritten as $\sigma-1\leq\mu+O\left(\frac{1}{N}\right)$. Differentiating (25) with respect to N gives

$$\frac{d\pi^{*}}{dN}=\frac{v(N)}{\mu\left[N\varepsilon^{YH}\right]^{2}}$$

[11] In the analysis the number of firms is treated as a continuous variable so the propositions are formally valid for a marginal increase. The results are valid for a discrete increase provided the increase does not cause the number of firms to cross the various critical values defined in the propositions.

N	2	3	4	5	6	7	8
π^*	0.0240	0.0198	0.0269	0.0297	0.0301	0.0294	0.282

Table 1: Competition and individual profit

where $v(N)$ is a cubic polynomial in $\frac{1}{N}$ such that

$$v(N) = \sigma(\sigma - 1 - \mu) + O\left(\frac{1}{N}\right). \tag{28}$$

Therefore, as long as the profits are positive in equilibrium, $\frac{d\pi^*}{dN} < 0$ for sufficiently large N, and $\lim_{N\to\infty} \pi^* = 0$.

For small N the equilibrium profit can change non-monotonically with N. Although the roots of $v(N)$ can be expressed in closed form in terms of $\{\gamma, \mu, \sigma\}$, the expressions are cumbersome and give little insight. Instead, we use a numerical example in Table 1 to illustrate a non-monotonic pattern in π^*. In this example, for $\gamma = 5$, $\sigma = \mu = 1.6$, individual profit falls when the number of firm increases from 2 to 3, then increases monotonically starting from $N = 3$, and starts falling from $N = 6$.

The aggregate profit of the monopolistically competitive sector can also exhibit a non-monotonic pattern, depending on the elasticity of demand and the elasticities of the production and quality cost functions. The complete characterization of the behaviour of $\Pi^*(N)$ is given in proposition 2. It is surprising to observe that aggregate profit can rise or fall as the number of firms increases but, if it ever does fall, then it must eventually start to rise again. This property is counter to that of the standard model.

Proposition 2 *When the number of firm increases:*
(i) if $\sigma - 1 > \frac{4(1+\mu)}{\gamma\mu}$*, aggregate profit rises;*
(ii) if $\sigma - 1 < \frac{4(1+\mu)}{\gamma\mu}$*, there exists* $N^* > 2$ *such that aggregate profit falls for* $N < N^*$ *and rises for* $N > N^*$*.*

We now investigate how a change in the number of firms affects consumer utility. In a symmetric equilibrium indirect utility is given by

$$V(N) = V_0 N^{1/(\sigma-1)-\gamma-1/\mu} \left[\frac{\varepsilon^{YH} - 1}{\varepsilon^{YH}}\right]^{1+\gamma+1/\mu},$$

where $V_0 = I^{1+\gamma+1/\mu} \frac{(\gamma\eta)^\gamma}{\beta} \left[\frac{1-\xi}{\mu}\theta_1\right]^{1/\mu}$. The effect upon utility is described in the following proposition.

Proposition 3 *Given* $\{\gamma, \mu\}$ *there exist* $\underline{\sigma} < \overline{\sigma}$ *such that, when the number of firms increases,*
(i) if $\sigma < \underline{\sigma}$*, utility increases;*
(ii) if $\underline{\sigma} < \sigma < \overline{\sigma}$*, there exists* $\widetilde{N} > 2$ *such that utility increases for* $N < \widetilde{N}$ *but decreases for* $N > \widetilde{N}$*;*
(iii) if $\sigma \geq \overline{\sigma}$ *utility falls for all* $N \geq 2$*.*

N	2	3	4	5	6	7	8	9
V/V_0	0.0114	0.0170	0.0186	0.0187	0.0183	0.0177	0.0170	0.0164

Table 2: Competition and consumer utility

Here $\underline{\sigma} = 1 + \frac{1}{2\left(\gamma + \frac{1}{\mu}\right)}$, and the expression for $\overline{\sigma}$ is given in the Appendix. The behaviour of utility is monotone for sufficiently large N, but can be non-monotone for small N, depending on the values of γ, μ, and σ. When the cost effect is weak ($\gamma < \frac{1}{2(\sigma-1)} - \frac{1}{\mu}$), the production cost effect is dominated by the market share effect, so that with the number of firms rising the equilibrium price falls and utility increases. On the other hand, larger values of γ imply a steeper rise in the marginal cost as environmental quality deteriorates. Free-riding leads to high production cost and, hence, higher prices, and when the cost effect is very strong utility falls as the number of firms increases.

Table 2 illustrates the non-monotonic pattern in utility when $\gamma = 1,\ \sigma = 1.6$, and $\mu = 1.5$. In this case, $\widehat{\sigma} = 1.3 < \sigma = 1.6 < \overline{\sigma} \approx 2.11$, which corresponds to case (ii), with $\widetilde{N} = 4.61$.

To understand how competition affects social welfare it is necessary to consider aggregate profit and consumer utility. The social welfare analysis is based on the use of a compensation argument. As the number of firms changes, the aggregate profit of the producers and the utility of the consumers change. Clearly, social welfare falls if both profit and utility fall, and rises if both rise. When profits and utility change in opposite directions, we identify a social welfare increase as occurring when the winners can compensate the losers. That is, if the increase in profit exceeds the additional income required by consumers as compensation, or if the consumers can compensate firms by transferring income to them to restore lost profitability, then a social welfare increase is obtained.

The change in profit and utility caused by a change ΔN in the number of firms can be approximated by $\Delta\Pi \simeq \frac{d\Pi}{dN}\Delta N$ and $\Delta V \simeq \frac{\partial V}{\partial N}\Delta N$. Suppose that $\Delta V < 0$ and $\Delta\Pi > 0$. Take ΔI from the firms and transfer it to the consumer so that the transfer returns the consumer to the original level of utility, so $\frac{\partial V}{\partial N}\Delta N + \frac{\partial V}{\partial I}\Delta I = 0$. Then social welfare increases if profits do not fall below the original level

$$\Delta\Pi + [-\Delta I] = \left(\frac{d\Pi}{dN} + \frac{\frac{\partial V}{\partial N}}{\frac{\partial V}{\partial I}}\right)\Delta N \geq 0.$$

It can be seen that if the change ΔN causes profit to fall and utility to rise, a transfer ΔI from the consumer to the firms gives the same condition for a welfare increase.

The results in this section have shown that for a large range of the parameters consumer utility and producer profit move in opposite directions as the number of firms changes. Therefore, the effect of competition on social welfare will depend on which of these two components dominates. Denoting $\frac{dW}{dN} \equiv \frac{d\Pi}{dN} + \frac{\frac{\partial V}{\partial N}}{\frac{\partial V}{\partial I}}$, the change in the social welfare is given by

$$\frac{dW}{dN} = \frac{I}{N}\left[\frac{\frac{1}{\sigma-1} - \gamma - \frac{1}{\mu}}{1 + \gamma + \frac{1}{\mu}} + \frac{\gamma}{N} + \frac{1}{N\left(\varepsilon^{YH}\right)^2}\left[\frac{N}{(N-1)} - \frac{\sigma-1}{\mu} - \gamma\sigma\right]\right].$$

Clearly, $\frac{dW}{dN} = O\left(N^{-1}\right)$, and the leading term is $\frac{I}{N}\frac{\frac{1}{\sigma-1}-\gamma-\frac{1}{\mu}}{1+\gamma+\frac{1}{\mu}}$. Thus, for large N the sign of the change in welfare is determined by the sign of $\left(\frac{1}{\sigma-1} - \gamma - \frac{1}{\mu}\right)$. For small N, depending on the configuration of parameters and on the starting value, an increase in N may lead to an increase

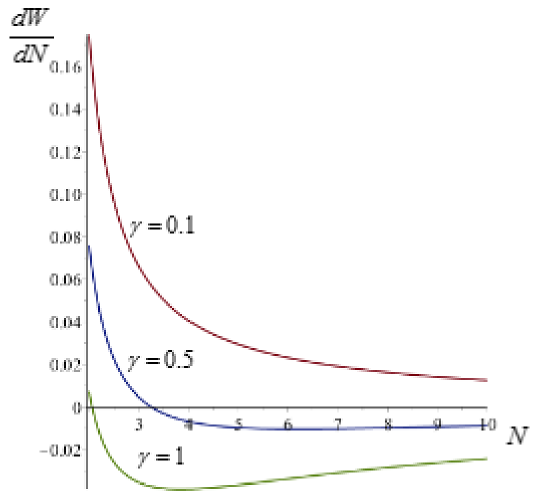

Figure 1: Competition and social welfare ($\sigma = \mu = 0.25$)

or a decrease in welfare. Importantly, there are cases for which an increase in the number of firms decreases profit sufficiently that the consumers are unable to compensate the firms.

These points are illustrated by the three cases shown in figure 1. In the first case, with $\gamma = 0.1$, the production cost externality is low, so there is little incentive for free-riding and more competition is always beneficial. The opposite is true in the third case with $\gamma = 1$ so a substantial externality. In the intermediate case, social welfare is maximal around $N = 3$; a further increase in the number of firms leads to a loss in aggregate profit which exceeds the gains accruing to the consumers.

5 Public Interest Defence

The public interest defence for allowing a cartel to operate is based on the argument that the additional profitability induces cartel members to make greater environmental contributions that more than offset the welfare loss due to non-competitive pricing. To address whether this defence can be sustained it is necessary to contrast the outcomes with and without a cartel. We know that a cartel will succeed in raising price relative to the Nash equilibrium, but the effect upon environmental expenditures is far less clear.

The results in the previous section have identified cases for which a reduction in competition (meaning a reduced number of active firms) raises welfare because environmental contributions increase. It might be argued that such results demonstrate a basis for the public interest defence but this is not a valid inference. Instead, the defence requires a demonstration that welfare is increased when a *fixed* number of firms cease competing and begin operating as a cartel. In a model with homogenous products and no environmental expenditures the formation of a cartel will reduce welfare. For example, a collusive duopoly will result in the monopolistic outcome, and monopoly generates lower welfare than duopoly. This reasoning cannot be applied so straightforwardly to the model with environmental contributions since collusion also affects the incentive to make the contributions. It is the consequences of this feature that we aim to assess.

The public interest defence requires that the creation of a cartel generates a welfare-enhancing increase in non-market benefits. To address this the Nash equilibrium with no cartel is taken as the starting point and the introduction of cartel power is modelled as causing an increase in price. Formally we adopt a reform perspective: the market price becomes the control variable (a cartel will always set a higher price than competing firms) and the other choice variables adjust optimally to the price. It is then possible to determine whether the welfare loss due to the price increase is more that offset by a gain from increased environmental contributions. If this is the case, the analysis provides support for the public interest defence. If the converse is true, then the public interest defence fails.

The approach to the analysis is to suppress the first-order condition for price and solve the remaining conditions treating price as a parameter of the system. It is assumed that the equilibrium is symmetric so that there is a common equilibrium price, and the environmental expenditures are determined as functions of the price. With price equal to the Nash equilibrium value the environmental expenditures will be equal to our existing solutions. Starting from an arbitrary initial price, the consumer loses directly from any price increase (in a standard model this alone more than offsets the increase in profit). Because the brand image expenditures rise, for the sufficiently low prices the benefit from higher perceived environmental quality of the products outweighs the loss from higher price. When the price hits a threshold (identified in the appendix), the negative effect of a further increase in price dominates, and utility falls. Since this threshold is lower than the Nash equilibrium price under monopolistic competition we can conclude that any further increase in price by the cartel can only reduce the consumer utility.

These observations are summarized in the central result of the paper.

Theorem 1 *An increase in price by a cartel above the Nash equilibrium price:*
(i) decreases the aggregate environmental quality,
(ii) decreases the direct environmental contributions of individual firms,
and
(iii) decreases consumer utility.

The crucial part of theorem 1 is that total environmental quality is decreasing in p. As shown in the Appendix,

$$e = \left(\frac{\eta I \gamma \beta}{N p} \right)^{1/(1+\gamma)},$$

from which it can be seen directly that e is decreasing in p and N. Therefore, a large cartel leads to lower environmental quality than a small cartel for a given level of price. Which of a large or small cartel leads to the lowest level of environmental quality depends on the interplay between cartel size and the ability to sustain a higher price. Because of the optimization of the firms belonging to the cartel, the envelope condition removes the effect of environmental contributions on profit. The intuition behind this result is that environmental expenditures are made for strategic reasons. This is the case whether they create have public benefits for the firms (the direct expenditures) or private benefits (brand image expenditures). The formation of a cartel reduces the need for the direct strategic expenditures so the level falls as a consequence.

From this analysis follows the conclusion that there is no grounds for the cartel defence based on public interest. If the cartel is permitted to raise price above the Nash equilibrium level with monopolistic competition it reduces contribution to the public good, and aggregate environmental quality falls. The competing firms have strategic reasons to make individual environmental contributions but these are reduced as the cartel becomes more successful. This outcome undermines the very reason for allowing the firms to cartelize. Moreover, the benefit accruing to the consumers in the form of higher product quality is outweighed by the loss caused by the higher price. This violates the central criterion of public interest defence requiring the fair share of benefit to accrue to the consumers.

6 Conclusions

Corporations make significant environmental contributions and must expect some commercial advantage from doing so. We have modelled two forms of benefit: an improved environment reducing production cost, and increased demand through cultivation of an environmental brand image. These benefits have very different effects upon the strategic interaction among producers.

An improved environment is a public good that benefits all firms; as a result, strategic interaction in contribution to this public good is added to the strategic interaction in the market place. The consequence is that reduced competition benefits the environment since it reduces the free-rider effect. This can potentially lead to social welfare increasing as the number of competing firms is reduced despite the consumer preference for variety. Brand image is a form of non-price competition and has only private benefits for firms. In the absence of externalities, increased competition is preferable when there is no direct environmental benefit from brand image.

Combining these two interpretations of environmental contribution allows us to address the public interest defence in a rich analytical framework. Even though there is a wide range of effects at work we are able to demonstrate that cartelization will be harmful to the public interest. The change in the strategic environment that results from the formation of a cartel leads to a lower environmental quality and to fall in consumer utility. The utility loss stems from higher prices which outweighs the benefit from the higher perceived quality of goods by the consumers. Therefore, even though the firms provide voluntary environmental contributions, the public interest defence is not sustained .

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Appendix

Proof of Lemma 1 Firm j maximizes profit:

$$\max_{\left\{p_j, E_j^1, E_j^2, E_j\right\}} \pi_j = \left[p_j - c\left(e\right)\right] q_j - E_j.$$

The first-order condition for choice of p_j is

$$\frac{\partial \pi_j}{\partial p_j} = q_j + \left[p_j - c\left(e\right)\right]\left[\frac{\partial q_j}{\partial p_j} + \frac{\partial q_j}{\partial P_Z}\frac{\partial P_z}{\partial p_j}\right] = 0.$$

Using (5)

$$\frac{p_j - c\left(e\right)}{p_j} = \left[\sigma - \left(\sigma - 1\right) s_j\left(N\right)\right]^{-1},$$

where $s_j\left(N\right) = \frac{1}{N}\left[\frac{p_j/z_j}{P_Z}\right]^{1-\sigma}$. Solving for p_j gives (14).

The first-order condition for E_j^1 is

$$\frac{\partial \pi_j}{\partial E_j^1} = -c'\left(e\right)\frac{\partial e}{\partial E_j^1} q_j + \left[p_j - c\left(e\right)\right]\left[\frac{\partial q_j}{\partial z_j} + \frac{\partial q_j}{\partial P_Z}\frac{\partial P_z}{\partial z_j}\right]\frac{\partial z_j}{\partial z_j^1}\frac{\partial z_j^1}{\partial E_j^1} = 0, \tag{29}$$

From (11) we have

$$\frac{\partial z_j^k}{\partial E_j^k} = \frac{1}{C_k'\left(z_j^k\right)}, \quad k = 1, 2. \tag{30}$$

From (13) we have

$$\frac{\partial e}{\partial E_j^1} = -\left(2\eta - 1\right).$$

Using these two conditions (29) can be written as

$$-\left(2\eta - 1\right) c'\left(e\right) q_j = \left[p_j - c\left(e\right)\right]\left[\frac{\partial q_j}{\partial z_j} + \frac{\partial q_j}{\partial P_Z}\frac{\partial P_z}{\partial z_j}\right]\frac{\partial z_j}{\partial z_j^1}\frac{1}{C_1'\left(z_j^1\right)}.$$

This can be rearranged as

$$
\begin{aligned}
-(2\eta-1)\,C_1'\left(z_j^1\right)c'(e) &= \frac{p_j-c(e)}{q_j}\left[\frac{\partial q_j}{\partial z_j}+\frac{\partial q_j}{\partial P_Z}\frac{\partial P_z}{\partial z_j}\right]\frac{\partial z_j}{\partial z_j^1} \\
&= [p_j-c(e)]\left[\frac{z_j}{q_j}\frac{\partial q_j}{\partial z_j}+\frac{P_Z}{q_j}\frac{\partial q_j}{\partial P_Z}\frac{z_j}{P_z}\frac{\partial P_z}{\partial z_j}\right]\frac{1}{z_j}\frac{\partial z_j}{\partial z_j^1}. \qquad (31)
\end{aligned}
$$

For the quality-adjusted Dixit-Stiglitz preferences

$$
\frac{z_j}{q_j}\frac{\partial q_j}{\partial z_j}=\frac{P_Z}{q_j}\frac{\partial q_j}{\partial P_Z}=\sigma-1,\quad \frac{z_j}{P_z}\frac{\partial P_z}{\partial z_j}=-\frac{1}{N}\left[\frac{p_j/z_j}{P_Z}\right]^{1-\sigma}=-s_j(N),
$$

and from the first-order condition for price

$$
p_j-c(e)=\frac{c(e)}{(\sigma-1)\left[1-s_j(N)\right]} \qquad (32)
$$

Therefore, (31) becomes

$$
-(2\eta-1)\,C_1'\left(z_j^1\right)c'(e)=c(e)\,\frac{1}{z_j}\frac{\partial z_j}{\partial z_j^1}. \qquad (33)
$$

From (10) we have

$$
\frac{\partial z_j}{\partial z_j^1}=(1-\xi)\,\frac{z_j}{z_j^\alpha}\left(z_j^1\right)^{\alpha-1}
$$

Substituting into (33) gives

$$
-(2\eta-1)\,z_j^1C_1'\left(z_j^1\right)c'(e)=c(e)\,(1-\xi)\left(\frac{z_j^1}{z_j}\right)^\alpha.
$$

Rearranging this condition gives (15).

The first-order condition for E_j^2 is

$$
\frac{\partial \pi_j}{\partial E_j^2}=-c'(e)\,\frac{\partial e}{\partial \delta_j^2}q_j+[p_j-c(e)]\left[\frac{\partial q_j}{\partial z_j}+\frac{\partial q_j}{\partial P_Z}\frac{\partial P_z}{\partial z_j}\right]\frac{\partial z_j}{\partial z_j^2}\frac{\partial z_j^2}{\partial E_j^2}=0. \qquad (34)
$$

Rearranging and dividing the (29) by (34), gives

$$
\frac{\partial e/\partial E_j^1}{\partial e/\partial E_j^2}=\frac{\partial z_j/\partial z_j^1}{\partial z_j/\partial z_j^2}\frac{\partial z_j^1/\partial E_j^1}{\partial z_j^2/\partial E_j^2}.
$$

Using (13) and (10) this condition becomes

$$
\frac{2\eta-1}{\eta}=\frac{1-\xi}{\xi}\left[\frac{z_j^1}{z_j^2}\right]^{\alpha-1}\frac{\partial z_j^1/\partial E_j^1}{\partial z_j^2/\partial E_j^2}. \qquad (35)
$$

Substituting from (30) into (35) gives (16). Condition (17) follows directly from differentiation of profit.

Proof of Lemma 2 Using (19) to substitute into (16) gives

$$z_j^2 = \left(\frac{1-\xi}{\xi} \frac{\theta_1}{\theta_2} \frac{2\eta - 1}{\eta} \right)^{1/(\alpha-\mu)} z_j^1, \tag{36}$$

and, therefore, using (10)

$$z_j = z_j^1 \left[1 - \xi + \xi \left(\frac{1-\xi}{\xi} \frac{\theta_1}{\theta_2} \frac{2\eta - 1}{\eta} \right)^{\alpha/(\alpha-\mu)} \right]^{1/\alpha}. \tag{37}$$

Use (10) and substitute (37) into (15) to obtain

$$\frac{\mu}{\theta_1} \left(z_j^1 \right)^{\mu} = \frac{s_j \left(1 - s_j\right)}{\varepsilon_j^{YH}} \frac{1-\xi}{\omega} \left(\sigma - 1\right) I, \tag{38}$$

where

$$\omega = 1 - \xi + \xi \left(\frac{1-\xi}{\xi} \frac{\theta_1}{\theta_2} \frac{2\eta - 1}{\eta} \right)^{\alpha/(\alpha-\mu)} \tag{39}$$

Using (11), (19) and (5), this gives (20).

From (11) and (19)

$$E_2^j = \frac{\left(z_2^j \right)^{\mu}}{\theta_2}.$$

Using (36)

$$\begin{aligned} E_2^j &= \frac{\left(\frac{1-\xi}{\xi} \frac{\theta_1}{\theta_2} \frac{2\eta - 1}{\eta} \right)^{\mu/(\alpha-\mu)}}{\theta_2} \left(z_1^j \right)^{\mu} \\ &= \left(\frac{1-\xi}{\xi} \frac{2\eta - 1}{\eta} \right)^{\mu/(\alpha-\mu)} \left(\frac{\theta_1}{\theta_2} \right)^{\alpha/(\alpha-\mu)} E_1^j, \end{aligned}$$

which is (21).

Proof of Lemma 3

The proof determines the equilibrium value of e first and then deduces the expenditure, E, of each firm.

Rearrange (17) as

$$-\eta c'\left(e\right) \frac{p_j q_j}{p_j} = 1. \tag{40}$$

At at symmetric equilibrium $p_j q_j = \frac{I}{N}$. Use this fact and (14) to write (40) as

$$-\eta c'\left(e\right) \frac{I}{N} = c\left(e\right) \frac{\varepsilon_j^{YH}}{\varepsilon_j^{YH} - 1}. \tag{41}$$

Since $c\left(e\right) = \beta_j e^{-\gamma}$, substitution into (41) and rearrangement gives e as determined by (23).

At a symmetric equilibrium (12) gives

$$\begin{aligned} e &= N\left[\eta E - \eta E_1 - (2\eta - 1) E_2\right] \\ &= N\eta\left[E - E_1\left(1 + \frac{2\eta - 1}{\eta}\frac{E_2}{E_1}\right)\right]. \end{aligned} \tag{42}$$

Setting $s_j = \frac{1}{N}$ for the symmetric case in (20) and (21), and substituting these into (42) gives

$$e = N\eta\left[E - \frac{I}{\mu N}\frac{\varepsilon^{YH} - 1}{\varepsilon^{YH}}\right]. \tag{43}$$

Finally, substituting (23) into (43) and rearranging gives (22).

Proof of Proposition 1.

The overall level of environmental quality in a symmetric equilibrium is given by

$$e^* = \frac{\gamma\eta I}{N}\frac{\varepsilon^{YH} - 1}{\varepsilon^{YH}} = \gamma\eta I\left(\frac{1}{N} - \frac{1}{N\varepsilon^{YH}}\right) = \gamma\eta I\left(\frac{1}{N} - \frac{1}{N\sigma - (\sigma - 1)}\right),$$

and so

$$\begin{aligned} \frac{de^*}{dN} &= \gamma\eta I\left(-\frac{1}{N^2} + \frac{\sigma}{\left[N\sigma - (\sigma - 1)\right]^2}\right) \\ &= \frac{\gamma\eta I}{N^2\left[N\sigma - \sigma + 1\right]^2}\left(\sigma N^2 - \left[N\sigma - (\sigma - 1)\right]^2\right) \\ &= -\frac{\gamma\eta I}{N^2\left[N\sigma - \sigma + 1\right]^2}\left(N^2\sigma(\sigma - 1) - 2N\sigma(\sigma - 1) + (\sigma - 1)^2\right) \\ &= -\frac{\gamma\eta I\sigma(\sigma - 1)}{N^2\left[N\sigma - \sigma + 1\right]^2}\left(N^2 - 2N + \frac{\sigma - 1}{\sigma}\right). \end{aligned}$$

Observe that the quadratic polynomial in the last parentheses has two roots, $N^{\pm} = 1 \pm 1/\sqrt{\sigma}$, and, given $\sigma > 1$, $N^{\pm} < 2$. Therefore, this polynomial is positive for all $N > 2$, and so $\frac{de^*}{dN} < 0$ for all $N > 2$. Given the assumption $c'(e) < 0$, production cost increases with N.

Full expression for (28)

Differentiation of (25) with respect to N gives

$$\frac{\partial\pi^*}{\partial N} = \frac{I}{\mu\left[N\varepsilon^{YH}\right]^2}v(N),$$

where

$$\begin{aligned} v(N) &\equiv \sigma(\sigma - 1 - \mu) + \frac{2\sigma(\sigma - 1)(\gamma\mu - 1)}{N} \\ &\quad + \frac{(\sigma - 1)(\sigma - 1 - \gamma\mu(4\sigma - 1))}{N^2} + \frac{2\gamma\mu(\sigma - 1)^2}{N^3} \\ &= \sigma(\sigma - 1 - \mu) + O\left(\frac{1}{N}\right). \end{aligned}$$

Proof of Proposition 2

Differentiation of (26) with respect to N gives

$$\frac{d\Pi^*}{dN} = \frac{I\gamma\left(\sigma-1\right)^2}{\left[N\varepsilon^{YH}\right]^2}\widetilde{v}\left(\frac{1}{N}\right)$$

where

$$\widetilde{v}\left(x\right) = x^2 - 2px + q, \tag{44}$$

with

$$p = \frac{\sigma}{\sigma-1},\ q = \frac{\sigma}{\sigma-1} - \frac{1+\mu}{\gamma\mu\left(\sigma-1\right)}.$$

Using the discriminant, D, of the quadratic (44) we have

$$\frac{D}{4} = p^2 - q = \frac{\sigma}{\sigma-1}\left[\frac{\sigma}{\sigma-1} - 1\right] + \frac{1+\mu}{\gamma\mu\left(\sigma-1\right)} > 0,$$

and, therefore, the quadratic polynomial $\widetilde{v}\left(x\right)$ has two distinct real-valued roots,

$$x^{\pm} = p \pm \sqrt{p^2 - q},$$

such that

$$x^- > 0 \text{ and } x^+ > p > 1.$$

Moreover, $\widetilde{v}\left(x\right) > 0$ for $x < x^-$ or $x > x^+$, and $\widetilde{v}\left(x\right) < 0$ for $x^- < x < x^+$. Since we are interested in $N \geq 2$, two cases are possible:

(i) $x^- > 1/2$. Using the expressions for p and q, this gives, after obvious rearrangement, $\sigma - 1 > \frac{4(1+\mu)}{\gamma\mu}$. In this case $\widetilde{v}\left(x\right) > 0$ for all $x < x^-$, or $\frac{d\Pi^*}{dN} > 0$ for all $N > 2$

(ii) $x^- < 1/2$, or $\sigma - 1 < \frac{4(1+\mu)}{\gamma\mu}$. Then $\widetilde{v}\left(x\right) \gtrless 0$ for $x \lessgtr x^-$, and hence $\frac{d\Pi^*}{dN} \gtrless 0$ for $N \gtrless N^* = \frac{1}{x^-}$. This completes the proof.

Proof of Proposition 3 For arbitrary $N \geq 2$ the log-derivative of $V\left(N\right)$ gives

$$\begin{aligned}\frac{N}{V}\frac{dV}{dN} &= \frac{1}{\sigma-1} - 2\left(\gamma + \frac{1}{\mu}\right) + \frac{\gamma\mu\left(\gamma+\frac{1}{\mu}\right)}{n+1+\gamma\mu} + \frac{1+\gamma+\frac{1}{\mu}}{n} - \frac{\sigma-1}{\sigma}\frac{1+\gamma+\frac{1}{\mu}}{n+\frac{1}{\sigma}} \\ &\equiv v\left(n\right),\ n \equiv N-1.\end{aligned}$$

The function $v\left(n\right)$ is continuous and continuously differentiable for all $n \geq 1$, $\lim_{n\to\infty} v\left(n\right) = \frac{1}{\sigma-1} - 2\left(\gamma + \frac{1}{\mu}\right) \gtrless 0$ for $\sigma \lessgtr 1 + \frac{1}{2\left(\gamma+\frac{1}{\mu}\right)} = \widehat{\sigma}\left(\gamma,\mu\right)$, and $\lim_{n\to\infty} v'\left(n\right) = 0$. Furthermore, observe that $v\left(n\right)$ is strictly decreasing in n:

$$v'\left(n\right) = -\frac{\gamma\mu\left(\gamma+\frac{1}{\mu}\right)}{\left(n+1+\gamma\mu\right)^2} - \frac{1+\gamma+\frac{1}{\mu}}{n^2\left(n+\frac{1}{\sigma}\right)^2}\left[\frac{n^2}{\sigma} + 2\frac{n}{\sigma} + \frac{1}{\sigma^2}\right] < 0.$$

It is straightforward to show that

$$v\left(1\right) = -\frac{1}{\sigma^2-1}\left(a\sigma^2 + b\sigma + c\right),$$

where $a = \left(\gamma + \frac{1}{\mu}\right)\frac{4+\gamma\mu}{2+\gamma\mu}$, $b = -\left(3 + 2\left(\gamma + \frac{1}{\mu}\right)\right)$, $c = 1 + \left(\gamma + \frac{1}{\mu}\right)\frac{\gamma\mu}{2+\gamma\mu}$. Let σ^{+} and σ^{-} be the solutions of $v(1) = 0$: $\sigma^{\pm} = \frac{-b\pm\sqrt{b^2-4ac}}{2a}$. Since $a > 0$ and $a+b+c = -2 < 0$, we have $\sigma^{-} < 1 < \sigma^{+}$. Let $\overline{\sigma}(\gamma,\mu) = \sigma^{+}$. Then, $v(1) < 0$ for $\sigma > \overline{\sigma}$ and $v(1) > 0$ for $1 < \sigma < \overline{\sigma}$. Furthermore, one can show that $\overline{\sigma}(\gamma,\mu) > \widehat{\sigma}(\gamma,\mu)$ for all $\{\gamma,\mu\}$. Therefore, $v(n) < 0$ $\forall n \geq 1$ for $\sigma > \sigma_0$ and $v(n) > 0$ $\forall n \geq 1$ for $1 < \sigma < \widehat{\sigma}$. In the intermediate case, for $\widehat{\sigma} < \sigma < \overline{\sigma}$ by the intermediate value theorem $v(n) = 0$ for some $n_0 > 1$. Let $\widetilde{N} = n + 1$. This completes the proof.

Proof of Theorem 1

Fix the cartel prices at $\{p_j\}$. The remaining optimisation conditions are now solved to give the equilibrium choices as function of $\{p_j\}$.

The first-order condition for E_j^1 is

$$\frac{\partial \pi_j}{\partial E_j^1} = -q_j c'(e)\frac{\partial e}{\partial E_j^1} + [p_j - c(e)]\left[\frac{\partial q_j}{\partial z_j} + \frac{\partial q_j}{\partial P_Z}\frac{\partial P_z}{\partial z_j}\right]\frac{\partial z_j}{\partial z_j^1}\frac{\partial z_j^1}{\partial E_j^1} = 0, \tag{45}$$

From (11)

$$\frac{\partial z_j^k}{\partial E_j^k} = \frac{1}{C_k'\left(z_j^k\right)}, \quad k = 1, 2,$$

and from (13)

$$\frac{\partial e}{\partial E_j^1} = -(2\eta - 1).$$

Using these two conditions (45) can be written as

$$-(2\eta - 1)C_1'\left(z_j^1\right)c'(e) = [p_j - c(e)](\sigma - 1)(1 - s_j)\frac{1}{z_j}\frac{\partial z_j}{\partial z_j^1}. \tag{46}$$

Since

$$\frac{1}{z_j}\frac{\partial z_j}{\partial z_j^1} = \frac{1-\xi}{z_j^{\alpha}}\left(z_j^1\right)^{\alpha-1}$$

substituting into (46) gives

$$-(2\eta - 1)z_j^1 C_1'\left(z_j^1\right)c'(e) = [p_j - c(e)](\sigma - 1)(1 - s_j)(1 - \xi)\left(\frac{z_j^1}{z_j}\right)^{\alpha}. \tag{47}$$

From (37)

$$\begin{aligned} z_j &= z_j^1\left[1 - \xi + \xi\left(\frac{1-\xi}{\xi}\frac{\theta_1}{\theta_2}\frac{2\eta-1}{\eta}\right)^{\alpha/(\alpha-\mu)}\right]^{1/\alpha} \\ &= z_j^1\omega^{1/\alpha}, \end{aligned} \tag{48}$$

and the cost function

$$C_1\left(z_j^1\right) = \frac{\left(z_j^1\right)^{\mu}}{\theta_1}. \tag{49}$$

Substitute (48) and (49) into (46)

$$\frac{\mu}{\theta_1}\left(z_j^1\right)^{\mu}=\left[\frac{p_j-c\left(e\right)}{-c'\left(e\right)}\right]\left(\sigma-1\right)\left(1-s_j\right)\frac{1}{2\eta-1}\frac{1-\xi}{\omega}.$$

But, by definition,

$$E_j^1=C_1\left(z_j^1\right)=\frac{\left(z_j^1\right)^{\mu}}{\theta_1}, \tag{50}$$

which gives

$$E_j^1=\frac{1}{\mu}\left[\frac{p_j-c\left(e\right)}{-c'\left(e\right)}\right]\left(\sigma-1\right)\left(1-s_j\right)\frac{1}{2\eta-1}\frac{1-\xi}{\omega}. \tag{51}$$

The remaining necessary conditions for the optimization of firm j are

$$\frac{C_1'\left(z_j^1\right)}{C_2'\left(z_j^2\right)}=\frac{2\eta-1}{\eta}\frac{1-\xi}{\xi}\left[\frac{z_j^1}{z_j^2}\right]^{\alpha-1}, \tag{52}$$

and

$$-\eta c'\left(e\right)q_j-1=0. \tag{53}$$

From (53)

$$-c'\left(e\right)q_j\frac{p_j}{p_j}=\frac{1}{\eta},$$

and at a symmetric equilibrium

$$pq=\frac{I}{N},$$

so

$$c'\left(e\right)=-\frac{1}{\eta}\frac{N}{I}p,$$

Using the definition of $c\left(e\right)$

$$\gamma\beta e^{-(\gamma+1)}=\frac{1}{\eta}\frac{N}{I}p$$

which can be solved to give the aggregate environmental quality as a function of p and N:

$$e=\left(\frac{\eta I\gamma\beta}{Np}\right)^{1/(1+\gamma)}. \tag{54}$$

Clearly, $\frac{de}{dp}<0$. This proves part (i) of the theorem.

Next, write (51) at the symmetric equilibrium as

$$\begin{aligned}E^1 &= \frac{1}{\mu}\left[\frac{p}{-c'\left(e\right)}-\frac{c\left(e\right)}{-c'\left(e\right)}\right]\left(\sigma-1\right)\left(1-s_j\right)\frac{1}{2\eta-1}\frac{1-\xi}{\omega}\\ &= \frac{1}{\mu}\left[\frac{\eta I}{N}-\frac{1}{\gamma}e\right]\left(\sigma-1\right)\left(1-s_j\right)\frac{1}{2\eta-1}\frac{1-\xi}{\omega},\end{aligned}$$

and use (54) to give the solution

$$E^1=\left[\frac{\eta I}{N}-\frac{1}{\gamma}\left(\frac{\eta I\gamma\beta}{Np}\right)^{1/(1+\gamma)}\right]\frac{N-1}{N}\frac{\sigma-1}{2\eta-1}\frac{1-\xi}{\mu\omega}. \tag{55}$$

Thus, the expenditure on the nominal quality improvement, which do not contribute to the improvement of environment, increase as price increases.

To obtain E_j^2 use (52) and $C_i\left(z_j^i\right) = \frac{\left(z_j^i\right)^\mu}{\theta_i}$ to give

$$z_j^2 = z_j^1 \left(\frac{\theta_1}{\theta_2}\frac{2\eta - 1}{\eta}\frac{1-\xi}{\xi}\right)^{\frac{1}{\alpha-\mu}}.$$

Since

$$E_j^1 = C_1\left(z_j^1\right),\ E_j^2 = C_2\left(z_j^2\right),$$

it follows that in a symmetric equilibrium

$$\begin{aligned} E^2 &= \frac{\left(z^1\right)^\mu}{\theta_1}\frac{\theta_1}{\theta_2}\left(\frac{\theta_1}{\theta_2}\frac{2\eta-1}{\eta}\frac{1-\xi}{\xi}\right)^{\frac{\mu}{\alpha-\mu}} \\ &= E^1\frac{\theta_1}{\theta_2}\left(\frac{\theta_1}{\theta_2}\frac{2\eta-1}{\eta}\frac{1-\xi}{\xi}\right)^{\frac{\mu}{\alpha-\mu}} \\ &= \left[\frac{\eta I}{N} - \frac{1}{\gamma}\left(\frac{\eta I\gamma\beta}{Np}\right)^{1/(1+\gamma)}\right]\frac{N-1}{N}\frac{\sigma-1}{2\eta-1}\frac{1-\xi}{\mu\omega}\frac{\theta_1}{\theta_2}\left(\frac{\theta_1}{\theta_2}\frac{2\eta-1}{\eta}\frac{1-\xi}{\xi}\right)^{\frac{\mu}{\alpha-\mu}}. \end{aligned} \tag{56}$$

Clearly, expenditure on the real quality improvement also increases as price increases.

Since, as we have shown above, aggregate environmental quality falls as price increases, it must be the fall in the direct contributions to the improvement of environment, E^3, which causes the overall negative effect of an increase in price: in a symmetric equilibrium

$$\begin{aligned} \frac{de}{dp} &= (1-\eta)N\frac{dE^1}{dp} + \eta N\frac{dE^3}{dp}, \\ \frac{de}{dp} &< 0,\ \frac{dE^1}{dp} > 0 \Rightarrow \frac{dE^3}{dp} < 0. \end{aligned}$$

This proves part (ii) of the theorem.

Indirect utility is given by $V = \frac{I}{P_Z}N^{1/\sigma-1}$, where $P_Z = \left[\frac{1}{N}\left(\sum_{i=1}^N\left(\frac{p_i}{z_i}\right)^{1-\sigma}\right)\right]^{1/(1-\sigma)}$, and in the symmetric equilibrium $P_Z = \frac{p}{z}$. Thus,

$$\frac{1}{V}\frac{dV}{dp} = -\frac{1}{p} + \frac{1}{z}\frac{dz}{dp} = -\frac{1}{p} + \frac{1}{\mu E_1}\frac{dE_1}{dp},$$

where the last equality is obtained using (48) and (50). Finally, using (55),

$$\frac{1}{E^1}\frac{dE^1}{dp} = \frac{1}{p}\frac{\frac{1}{\gamma(1+\gamma)}\left(\frac{\eta I\gamma\beta}{Np}\right)^{1/(1+\gamma)}}{\left[\frac{\eta I}{N} - \frac{1}{\gamma}\left(\frac{\eta I\gamma\beta}{Np}\right)^{1/(1+\gamma)}\right]}.$$

Note that the denominator is strictly positive as long as $p > c(e)$. Then,

$$\begin{aligned}\frac{1}{V}\frac{dV}{dp} &= -\frac{1}{p}\left[1-\frac{1}{\mu}\frac{\frac{1}{\gamma(1+\gamma)}\left(\frac{\eta I\gamma\beta}{Np}\right)^{1/(1+\gamma)}}{\left[\frac{\eta I}{N}-\frac{1}{\gamma}\left(\frac{\eta I\gamma\beta}{Np}\right)^{1/(1+\gamma)}\right]}\right] \\ &= -\frac{1}{p}\frac{\frac{\eta I}{N}-\frac{1}{\gamma}\left(\frac{\eta I\gamma\beta}{Np}\right)^{1/(1+\gamma)}\left(1-\frac{1}{\mu(1+\gamma)}\right)}{\frac{\eta I}{N}-\frac{1}{\gamma}\left(\frac{\eta I\gamma\beta}{Np}\right)^{1/(1+\gamma)}} \lesseqgtr 0\end{aligned}$$

iff

$$\frac{\eta I}{N}-\frac{1}{\gamma}\left(\frac{\eta I\gamma\beta}{Np}\right)^{1/(1+\gamma)}\left(1-\frac{1}{\mu(1+\gamma)}\right) \gtreqless 0.$$

Thus, if $\mu(1+\gamma) < 1$ then $\frac{1}{V}\frac{dV}{dp} < 0$ for any $p > 0$, and if $\mu(1+\gamma) > 1$ then

$$\frac{1}{V}\frac{dV}{dp} < 0 \iff p > \beta\left[\frac{N}{\gamma\eta I}\right]^{\gamma}\left[\frac{\mu(1+\gamma)-1}{\mu(1+\gamma)}\right]^{1+\gamma} \equiv \overline{p}.$$

One can see immediately that $\overline{p} < p^*$, the Nash equilibrium price (24), since

$$\overline{p} = \beta\left[\frac{N}{\gamma\eta I}\right]^{\gamma}\left[\frac{\mu(1+\gamma)-1}{\mu(1+\gamma)}\right]^{1+\gamma} < \beta\left[\frac{N}{\gamma\eta I}\right]^{\gamma} < \beta\left[\frac{N}{\gamma\eta I}\right]^{\gamma}\left[\frac{\varepsilon^{YH}}{\varepsilon^{YH}-1}\right]^{1+\gamma} = p^*.$$

Therefore, $\frac{dV}{dp} < 0$ for any $p > p^*$. This completes the proof of part (iii).