Collective Reputation and Market Structure: Regulating the Quality vs Quantity Trade-off

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This version: December 2007

Abstract

Between market unraveling and individual reputation building, markets for experience goods often exhibit intermediate patterns. This paper explores the situation in which consumers know the average quality offered by a set of producers, but not the quality of one given product. A first issue is how such an aggregate signal shapes competition when strategic variables are quantity and quality. The equilibrium welfare function is convex in the number of competing firms as a consequence of decreasing quality and increasing quantity. A second issue is regulation. It is possible to trade-off quantity against quality through a number of regulatory tools. Among one-instrument policies, entry and quantity regulation perform better than price-based regulation. Policy implications for professional regulation in service markets and producers' organisations in agriculture are briefly discussed.

JEL: D4, L1, L43, Q13

Keywords: Uncertain Quality, Market Structure, Collective Reputation, Minimum Quality Standard.

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This paper was mostly written when the author was affiliated to INRA.

I am grateful to Jean-Marc Bourgeon, Igor Mouraviev, Sébastien Lecocq, Hervé Tanguy and Eric Giraud-Héraud for comments and discussions. This paper also benefited from comments by seminar participants at INRA (Paris-Ivry) and AgroParisTech as well as by participants to the 23èmes JMA (Nantes), EARIE 2006 (Amsterdam) and EEA 2007 (Budapest). Partial support from the Ecole Polytechnique Chair in Business Economics is gratefully acknowledged.

1 Introduction

Since Akerlof (1970), economists tend to predict that when quality is unknown, low quality products drive high quality ones out of the market. Consider a consumer's (she) buying decision when she is not sure about the quality of the good: she is not ready to pay more than the *expected* quality. But since she does not observe the quality choice, these expectations do not depend on what the buyer actually does. Then he has no incentive to produce (costly) quality. Therefore the only equilibrium expectations the consumer can hold is that the producer sells the lowest quality: market for high quality thus unravels. In this paper, we study how market functions when consumers do know average quality present on the market, but not that of one given product. This represents an intermediate situation between the perfect information setting and the asymmetric information setting. The information publicly available consists of a global assessment of quality. This (true) average quality is the result of the strategic choices by many producers.

Undoubtfully, unraveling may be prevented when the consumer repeatedly purchases from the same supplier: after experiencing a bad quality product- or service, she can decide to stop buying it (and potentially buy another one), which disciplines the supplier. This is the essence of brand building by firms, that can be modeled by a repeated purchase game (Heal, 1976) and is referred to as 'reputation' in game theoretical studies (see for example Shapiro, 1982, 1983). However, this solution requires first that the relationship is long lasting, and second that the producing firm is identified at each purchase. The latter condition fails when identity of the producer is lost in the retailing chain (e.g. there is no traceability), when the frequency of purchased is low enough (in particular for specialized services) or when the consumer has bounded memory and limited cognitive capacities. As a leading example of product subject to such restrictions, consider the case of French wines. Except for famous *Chateaux*, the relevant information for the standard consumer boils down to the region and year of production[1]. What the consumer refers to in such a case is rather a public knowledge that the kind of wine has some average quality, a fact that has received strong empirical support (see for example Landon and Smith, 1998). How such a public signal is generated is not the subject of the paper, and it is already a thoroughly investigated topic. This signal can

[1] On this, see the evidence in Combris et al. (1997). In the United States and emerging wine countries, this information consists rather of brand and type of vine.

be provided by experts[2], by certification bodies[3] or by discussion with other buyers through various kinds of consumers networks, a topic yet understudied by economists[4]. This public signal is different from a "reputation" in the sense that it is not based on past consumptions of a similar product, but instead relies on expert judgment, or on the consumption of the *same* generation of product (instead of a past product of the same brand) by other consumers. In short, the emergence of such a public knowledge regarding average quality is not inter-temporal, but has to do with the formation of quality expectation regarding a one-shot production[5]. As concerns expert ratings, they even preempt public consumption: It is indeed the very role of premieres and journalists of specialized press to provide the public with an evaluation of products before purchase takes place. Again, the case of wine where experts are the first to taste and to give an overall appreciation for a given region for the current year is illustrative. We assume here that the experts are reliable[6], so that the customers can rely on an objective reference when buying the experience good.

The setting under study here is a Cournot oligopoly with endogenously differentiated experience goods. Producers choose both quality and quantity, and consumers know average quality despite the fact that they do not identify producers individually. An important focus is on the comparative statics with respect to n, the number of competitors: Under relatively mild assumptions, we demonstrate equilibrium existence and uniqueness for any number of competitors. While total marketed quantity is increasing in n, quality is decreasing, yielding a U-shaped welfare as a function of n. This implies that either perfect competition or monopoly is the optimal market structure. This is so because of a free-riding effect on average quality: Essentially, the assumption on the information structure transforms the adverse selection problem into a moral hazard problem *à la* Holmström (1982). On the one hand, a monopoly, or a well-functioning producer organisation, chooses the socially optimal quality level because it is not subject to this moral hazard problem: average quality reveals directly the investment of the monopoly. But on the other hand, competition increases the quantities

[2] See in particular Ali et al. (2005) for an empirical estimation of Robert Parker's grades impact on Bordeaux prices, and the references therein on the topic of expert rating in wine, both at the brand and at the regional level.

[3] Among others, Lerner and Tirole (2006) and Peyrache and Quesada (2004) develop models in which the certification process is endogenous.

[4] For example, Curien et al. (2004) emphasize the importance of consumers' online networks.

[5] It is however perfectly possible to interpret the setting as a compact reputation model, embedding the dynamics effects in the one-period equilibrium.

[6] Of course, these experts may be subject to capture (see Strausz, 2005, for a representative recent contribution), but we will abstract here from this possibility.

sold. A second result is that the quantity effect is more than offset by the quality effect: competition happens to be harmful to the consumers if the enforceable quality standard is relatively low. In the limit, perfect competition can destroy all potential surplus when no quality standard is enforced. This result can explain the creation of agricultural syndicates that are not fought by governments, or even legally encouraged[7]. This result might also shed light on professional regulations such as in the medicine and law sectors.
With the two benchmarks of first-best and competitive situations in mind, we undertake the analysis of selective regulation of such markets. There is a room for regulation under any market structure. When quality standards are enforceable and stringent enough, perfect competition is close to the Pareto optimum - the usual convergence result of Cournot equilibrium to welfare-maximizing quantities hold when quality is (almost) not a concern. There is however a room for entry regulation when the standard is low. An important message here is that quality standards and competition are complementary under collective name. Finally, it is shown that among one-instrument policies, the best regulation tool is quantity regulation, which performs better than price regulation for any market structure.

2 Relation to the literature

The model is related to the collective reputation models of Tirole (1996), Winfree and McCluskey (2005) and Bourgeon and Coestier (2007), despite the static nature of the present analysis. Indeed, those papers are concerned with the dynamics of the problem, in absence of public signal. It turns out however that some conclusions are very similar, namely underprovision of quality, although in a different form. What mainly distinguishes the current analysis from the preceding ones is that we focus here on market structure and welfare analysis, the first topic being almost completely absent from the mentioned literature[8]. The assumptions there also differ from ours in many ways. Tirole (1996) considers a case where agents are of different types (honest, dishonest, or strategic): as is standard in reputation model (e.g. Kreps and Wilson, 1982), agents are exogenously different. Regarding the literature on experience goods, Moav and Neeman (2005) are interested in the role of the inspection technology with two classes of producers. Finally, the information setting studied

[7]See Title IV of the European Council Regulation No 1493/1999. Further developments on the case of wine can also be found in Giraud-Héraud et al. (2003).

[8]While dealing with a different problem - operating a regulated network - the model of Auriol (1998) also features a free-riding effect that can make (regulated) duopoly worse than (regulated) monopoly. However, the parallel ends here, because the cost structures and regulation problems are quite different.

here also differs from that considered by Wolinsky (1983), where consumers get independent private signal on the quality of each different product.

In the literature concerning agricultural producers organisation, many papers deals with close issues. Marette et al. (1999) and Marette and Crespi (2003) study certification and the role of these organisations, modeled as cartels[9]. Under the assumption of exogenous discrete quality, with consumers forming expectations about the quality of uncertified products, they show that cartels sharing the certification cost and colluding on quantities can do better that competition from a social point of view (intuitively, it happens when certification is individually too costly). Also, Auriol and Schilizzi (2003) studies the role of the (fixed) certification cost on market structure. Firms choose the socially optimum quality level as soon as they seek certification (be it public or private), and thus quality distortions comes only from non-certified firm, that produce the lowest quality. In their model, fixed certification cost has the following implications: when firms self-certified the market is oligopolistic, as expected with declining average costs. Next, they assume that it is possible no to duplicate these certification costs, and compare to possible certification arrangements: sharing costs proportionately to the quantity sold for each firm, or publicly funded. Concerning producers organisations, Winfree and McCluskey (2005) deal with collective reputation and use Shapiro (1983) setting, so they do not model endogenous learning of quality by the consumers: consumers do not form Bayesian expectations. Instead their beliefs evolve through a pre-specified Markovian process rather than through Bayesian revision. In addition, their paper only deals with producers surplus, without reference to the welfare impact.

The assumption of a public signal regarding average quality allows both to avoid ad hoc learning by consumers and to tackle the study of oligopoly, that, as Milgrom and Roberts mention, "involve significant additional problems" (1986, footnote 9) with respect to the monopoly case when quality is endogenous. Thus, beyond the realism embedded in it, this assumption also allows to go one step further, while keeping in a reduced form the problem of collective reputation. It also allows to treat in a unified framework all tools a regulator may want to use and compare their efficiency.

Finally, on the technical side, the result on equilibrium uniqueness obtained in the first

[9] Zago (1999) develops a mechanism design model to study collective decision within producers organisations in a related context.

part of this paper involves some difficulties that existing approaches can not overcome. The root of this difficulties lies on the one hand in the two-dimensional strategies of firms and on the other hand in the quality externality, a feature which is known to make quasi-concavity break down. In fact, the standard existence results similar to that of Rosen (1965), relying on differential calculus[10] do not apply due mainly to the lack quasi-concavity of the profit functions. The contraction mapping approach is not appropriate here because of two-dimensional strategy space (see Long and Soubeyran, 2000, for an elegant result regarding pure quantity competition), neither are the techniques of supermodular games and related tools (see Vives, 1999). Therefore, the proofs require specific treatments of the case under study, but by the same token provide specific insights on the collective reputation mechanics in oligopoly.

In the next section, the model is stated and its essential features are presented. The fourth section characterizes the competitive equilibrium. The fifth section is interested in the welfare properties of different market structures. Finally, the sixth section discuss regulation and policy implications while the last one concludes. All proofs are relegated to the appendix.

3 Model

3.1 The consumers

We consider a population of consumers that differ through their taste t for quality θ, where $\theta \in [\underline{\theta}, \overline{\theta}] \subset (0, +\infty)$. Consumers' tastes[11] are distributed over $[0, \bar{t}]$ according to the cumulative population weight $F(t)$. Following Mussa and Rosen (1978), a consumer with taste t facing a price p derives the following utility from buying one unit of a good with quality θ:

$$u(\theta, p; t) = \theta t - p$$

and she will buy (exactly one unit of) the good if $u(\theta, p; t) \geq 0$. The quantity sold is therefore $Q = F(\bar{t}) - F(\frac{p}{\theta})$, corresponding to the following inverse demand:

$$p = \theta F^{-1}\left(F(\bar{t}) - Q\right)$$

[10]See also Kolstad and Mathiesen (1987); Novshek (1985) and more recently Gaudet and Salant (1991).

[11]Setting the lowest taste at 0 yields an inverse demand function that does not discontinuously vanishes at some strictly positive quantity. Milgrom and Roberts (1986), for example, use a simplified version of this setting in their section II.

Under the stated preferences, the demand function is thus multiplicatively separable between the quality and quantity effects. We make the further assumption that the distribution of tastes is uniform, with weight K at each point, so that:

$$p(\theta, Q) = \theta(a - bQ) \tag{1}$$

with $a \equiv \bar{t}$ and $b \equiv \frac{1}{K}$.

An attractive property of the Mussa and Rosen specification of utility is that the inverse demand function (1) remains also valid when quality is imperfectly known, in which case θ represents then the expected quality[12]. This is true because consumers' utility is linear in θ. In addition, the assumption of uniform distribution also helps simplifying the inverse demand - although the linear-in-quantity formulation is illusory when it comes the case of expected quality, as will become clear. Much of the results could be derived without this linear functional form, although at the costs of much heavier technicalities.

We assume as thoroughly explained in the introduction that the consumers have some hard information about the actual quality sold in the market, more precisely:

Assumption 1 *Average quality and total quantity present on the market are public signals.*

This implies that consumers know for sure the average quality on the market ("strawberries are good this year", "most lawyers in this city are offer low quality service", and so on), but they are still unable to distinguish the quality of one precise product. Note that this assumption lies somewhere between the case of perfect information on each product sold and the pure Bayesian case, in which consumers only form expectations, based only on strategic considerations and not on public signal.

The fact that consumers know the total quantity (rather than, more realistically, the price), can be seen as a shortcut accounting for a retailing stage that transforms the quantity information into a price information. In fact, one could dispense with the assumption of publicly known quantity, at the cost of more sophistication in the price formation mechanism. One can notice that is also equivalent to assume that the consumers know exactly what each producer did, but can not identify afterwards where a given product comes from. We now turn to the production side, where quality and quantity are chosen.

[12]Leland (1979) studies a related model, but the micro-foundations are not explicit: he rather directly postulates a price-dependence on expected quality, and in addition he does not use imperfect competition as equilibrium concept.

3.2 The producers

There are n identical producers, indexed by $i = 1..n$, that choose their quantity q_i and quality θ_i, at a unit cost $c(\theta_i)q_i$, where c is strictly increasing and strictly convex, and satisfies the following conditions: $c(0) = 0$, $c'(0) = 0$ and $c'(\overline{\theta}) = +\infty$, which will ensure that some interior quality level is optimal. We impose also the technical assumption $c''' \geq 0$, whose role is explained when relevant. Note that we define the cost function independently of the minimum quality level, $\underline{\theta}$, so that we can study the effect of changing the minimum quality standard while holding the production technology fixed. This does not mean that it is legally feasible to sell the useless product with quality 0; in fact the lowest possible quality, $\underline{\theta}$, which has to be viewed as a minimum quality standard, is a fundamental policy tool whose impact is studied below.

We choose deliberately to consider costs functions that are linear in quantity. Indeed, to study the interplay of quality and quantity on the market structure, any other shape of costs[13] with regard to quantities would bias the optimal market structure towards one or the other direction, i.e. monopoly or perfect competition. With concave quantity costs, for example in the presence of a fixed cost, a more concentrated market would be socially preferred, while with convex quantity costs, spreading them among a very large number of producers would be desirable. As the focus is on the interaction between quality, quantity and market structure, we must get rid of such biases by neutralizing those technological effects, and the only functional form allowing that is the chosen multiplicative one.
The total quantity is denoted $Q = \sum q_i$, and the average quality on the market is:

$$\theta = \frac{\sum \theta_i q_i}{Q} \tag{2}$$

Given assumption 1, there is one single market price. Because the consumers are informed of the true average quality, this equilibrium price will be given by equation (1). Producer i's profit is therefore:

$$\pi_i(\{\theta_j, q_j\}) = p(\theta, Q)q_i - c(\theta_i)q_i \tag{3}$$

In the following we denote by Π the producers profit, with $\Pi = \sum \pi_i$.

[13]For example, Klein and Leffler (1981) have fixed costs depending on quality and Allen (1984) has both convex marginal costs *and* fixed costs, which makes the cost function neither concave nor convex. The present cost function is found for example in Besanko et al. (1987) and is rather standard in differentiated oligopolies models.

3.3 Welfare Optimum and benchmark case

In a first-best world, a benevolent social planner could assign to each producer a quality/quantity plan, to serve a predetermined set of consumers. That is, it would put in place a double-sided discrimination, with firms producing different levels of quality, corresponding to different market segments. In the limit, with a continuum of firms or, say, with free-entry, this amounts to a point-wise matching between firms and consumers, whose optimum is derived from a point-wise maximization for each consumer's taste. The quality menu $\theta(t)$ would verify:

$$c'(\theta(t)) = t$$

For a finite number of firms, the first-best optimum would consist of a partition of the consumers into quality groups, a discrete approximation of the above menu.

But that is not feasible when consumers can not discriminate between producers, as stated by assumption 1. Given that observability assumption, the consumers do not identify the different quality levels, which amounts to considering a single quality category, averaged over the different producers, and consequently there is a single associated price. This situation will constitute our benchmark second-best optimum. Hence we now consider the Marshallian consumer surplus defined by[14]:

$$U = \int_0^Q p(\theta, Q)dQ - p(\theta, Q)Q \tag{4}$$

For the demand function specified, this expression remains valid when quality is heterogenous, in which case θ is the average quality. Given the convexity of c, the cost for a given level of average quality is minimized when all producers choose exactly that quality level. In turn, since producers are identical and costs are linear with respect to quantity, allocation of production between the different producers is unimportant. The social optimum is therefore given by maximizing over θ and Q the following expression:

$$W = U + \Pi = \int_0^Q p(\theta, Q)dQ - c(\theta)Q$$

The corresponding first order conditions are:

$$\begin{cases} \theta^*(a - bQ^*) = c(\theta^*) \\ \int_0^{Q^*}(a - bQ)dQ = c'(\theta^*)Q^* \end{cases}$$

[14]It is of course equivalent to define it as $\int_{t_0}^{\bar{t}} u(t, \theta, p)dt$, where p denotes the equilibrium price and t_0 the consumer indifferent between buying or not.

which can be restated as:

$$Q^* = \frac{1}{b}(a - \frac{c(\theta^*)}{\theta^*}) \tag{5a}$$

$$c'(\theta^*) = \frac{1}{2}(a + \frac{c(\theta^*)}{\theta^*}) \tag{5b}$$

Of course, the problem is interesting if, first, an optimal level exists, that is, equation(5b) has a solution, and, second, this solution is higher than the minimum quality standard $\underline{\theta}$. The next lemma clarifies this.

Lemma 1 *Assume $c''' \geq 0$ and $c'(\underline{\theta}) < \frac{a}{2}$. Then θ^* is unique and $\theta^* > \underline{\theta}$.*

Once again, recall that this reference case is not a first-best situation, but rather constitutes the socially optimal production plan under the imperfect observability. In what follows, we will keep this assumptions, also they are not needed for all results.

4 Unconstrained Competition

Since there is a continuum of consumers and a finite number of firms (however large it can be), the consumption side of the market is assumed perfectly competitive. Therefore the firms face the demand schedule in (1). In turn, on the production side, there is imperfect competition: The producers play the Nash equilibrium of the game defined by strategies q_i, θ_i and payoffs in (3). Anticipating a bit on the results, we consider the first-order conditions of the profit, for some firm i (there are $2n$ first-order conditions overall).

$$\begin{cases} \frac{\theta_i - \theta}{Q}(a - bQ)q_i - b\theta q_i + \theta(a - bQ) - c(\theta_i) = 0 \\ \frac{q_i}{Q}(a - bQ)q_i - c'(\theta_i)q_i = 0 \end{cases}$$

To grasp some intuition on what is going on in equilibrium, assume that these conditions are indeed satisfied. Inspection of the first equation is especially instructive, so we rewrite it as follows:

$$p(\theta, Q) - c(\theta_i) = b\theta q_i + \frac{\theta - \theta_i}{\theta}\frac{q_i}{Q}p(\theta, Q) \tag{6}$$

The left-hand side is simply price minus marginal cost, and represents thus the unit margin. The right-hand side pertains to market power, and it decomposes into two effects. The first term is classically related to the elasticity of price with respect to quantity, as in any Cournot model. The second term is the keystone of the "collective quality" environment. It illustrates the quality dilution effect, which is positive when producer i chooses a lower than average quality, and therefore corresponds to a free-riding effect on quality. The magnitude of this effect also depends on he relative size ($\frac{q_i}{Q}$) of the considered producer, and on the absolute value of free-riding[15], namely the price.

As mentioned in the introduction, the game under study does not have a smooth structure. Clearly, the main difficulty comes from the the two-dimensional strategies, or alternatively, from the potential differentiation of the products in equilibrium, which makes the usual analysis with one single dimension fail. Indeed, from one firm point of view, it is not possible to deal with only one aggregate variable summarizing all the other firms' behavior. This implies that no general results apply to show equilibrium existence and uniqueness. To be precise, standard results for homogeneous Cournot competition (e.g. Kolstad and Mathiesen, 1987) have no bite in the present context, nor are the techniques in Vives (1999, p. 47) applicable.

The difficulties in characterizing the equilibrium are numerous, and we only mention here the most important ones. First, as is often the case in Cournot-like models, there might exist degenerate equilibria. The first lemma in the proof is dedicated to showing that it is not the case. For any number of firms, they are all active in equilibrium. Then, we demonstrate that there are only two kind of candidate equilibria (depending on whether the constraints associated with the minimum quality standard are binding), that happen to be symmetric. They can not coexist. Overall, we obtain existence and uniqueness of the equilibrium, that, when interior, is characterized by the two equations:

$$Q_n = \frac{n}{(n+1)b}(a - \frac{c(\theta_n)}{\theta_n}) \tag{7a}$$

$$c'(\theta_n) = \frac{1}{n+1}(\frac{a}{n} + \frac{c(\theta_n)}{\theta_n}) \tag{7b}$$

With a slight abuse of notation, we denote in the following by Q_n and θ_n the equilibrium values for the competitive equilibrium with n firms.

Proposition 1 *The game has a unique symmetric equilibrium. It has the following properties:*

(i) Quality is decreasing in the number of competitors, and there exists $N(\underline{\theta})$ *such that:*

[15] Note that if quality is exogenously set at some uniform level, the model collapses to a standard Cournot oligopoly with homogenous goods, and the free-riding effect disappears in that case.

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Figure 1: Equilibrium quality and quantity

$$\theta_{n+1} < \theta_n \textit{ for } 1 \leq n < N(\underline{\theta}) \textit{ and } \theta_n = \underline{\theta} \textit{ for } n \geq N(\underline{\theta})$$

(ii) Perfect competition drives quality to the lowest level:

$$\theta_\infty = \lim_{n\to\infty} \theta_n = \underline{\theta}$$

(iii) Total production is strictly increasing in the number of competitors.

(iv) For n large enough, competition induces overproduction:

$$Q_\infty = \lim_{n\to\infty} Q_n = \frac{1}{b}(a - \frac{c(\underline{\theta})}{\underline{\theta}}) > Q^*$$

The results are pictured in figure 1. The first two items are a consequence of free-riding on quality induced by average assessment of quality. The asymptotic result has to be paralleled with the well-known 'Commons Problem', where competitive consumption of a free-access resource drives production rents to zero. Here the producers' common resource is the average quality. Moreover, it is worth mentioning that, although intuitive, the results would not hold for any cost function: Dropping any one of the assumptions on the cost function would change in particular the uniqueness result. What seems more interesting is the overproduction associated with perfect competition. This is understood by remarking that since the marginal cost is smaller when quality is reduced, competitive price (equal to marginal cost) is also reduced. When the minimal quality is strictly smaller than the optimal one, this induces overproduction. Note finally that the monopoly quality is equal to the welfare-maximizing one. This is a feature of demands linear in quantity[16], but it is not essential.

As we have noticed earlier, each firm sees own quantity and own quality rather as complementary. But the result of proposition 1 states that quantity and average quality appear as substitute possibilities when market structure (e.g. the number of competitors) is the variable. In the next section, we explore the impact of this market equilibrium on welfare.

[16]See Spence (1975, proposition 2, p. 421 and note 7, p. 422). Under the micro-foundations used for the demand function, quality choice by a monopoly may be above or below the optimal demand, depending on the distribution of consumers.

5 Market structure and welfare

5.1 Consumers' surplus and the degree of competition

For any values Q and θ, consumers surplus is given by (4). Thus in the case of competition between n firms, we obtain:

$$\begin{aligned} U_n &= \int_0^{Q_n} p(\theta_n, Q)dQ - p(\theta_n, Q_n)Q_n \\ &= \frac{b}{2}\theta_n Q_n^2 \\ &= \frac{1}{2b}\theta_n(a - nc'(\theta_n))^2 \end{aligned}$$

where the last equality obtains using (6), and is valid whether the equilibrium quality is interior or not ($\theta_n = \underline{\theta}$). The ambiguous effect of enhanced competition decomposes as follows: while Q_n is increasing in n, θ_n is decreasing, which makes the variation of the product unclear. When the solution is not interior, it is however clear that welfare is increasing in n. Indeed, quality remains then at the lowest level, $\underline{\theta}$, for all n greater than $N(\underline{\theta})$, but quantity is increasing, which is beneficial. The next proposition gives the complete solution.

Proposition 2 *Let $N(\underline{\theta})$ be defined as in proposition 1. Consumers surplus is U-shaped with minimum at $N(\underline{\theta})$:*

$$U_n > U_{n+1} \text{ for all } n < N(\underline{\theta})$$
$$U_n < U_{n+1} \text{ for all } n \geq N(\underline{\theta})$$

This proposition allows to infer directly how welfare behaves overall.

Corollary 1 *Welfare is maximized either with a monopoly or with perfect competition.*

This is so because producers profit is decreasing with n, and vanishes completely in perfect competition. Compared to consumers surplus, considering welfare simply adds a decreasing trend, that increases the relative desirability of monopoly. A short remark is in order regarding fixed costs here. If the firms had a fixed production costs, say F, an additional trade-off would blur the picture. Indeed, the situation would then be one of natural oligopoly: Perfect competition would not make sense under that circumstance, because zero market profit would make entry unprofitable (with profit $-F$). The relevant comparison then would be between a monopoly and the maximal sustainable oligopoly, i.e. with k firms such that $\pi_{k+1} - F < 0 < \pi_k - F$. Equilibrium quantity and quality would behave as in proposition 1, but the optimal market structure would naturally be artificially biased towards a smaller

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Figure 2: Welfare under different market structures

number of firm. We do not want such considerations to interfere since our focus is on the market mechanism when only average quality is known. The next section is dedicated to the comparison of the two prominent market structures under no fixed costs, perfect competition and monopoly.

5.2 Monopoly, free entry and minimum quality standard

On the French wine market, private producers organisations (PO) have a real control over quantity sold, through surface yield reduction, forced distillation of low quality, planting rights and abandonment premiums[17]. Their decisions have to be validated at a centralized level, but are very seldom overruled. Moreover, an agreement by the PO is needed for commercializing wine-grape, which allows some quality checking. This organisation, in a rough approximation, can be compared to a form of monopoly. Thus its efficiency is probably close to that of the pure monopoly case of the present model. Now the question raised is how efficient this organization is with respect to free competition.
The monopoly situation deserves some attention. One can see that $\theta_1 = \theta^*$, which means that monopoly power does not distort quality here[18]. In turn, only half the optimal quantity would be produced in that case. Thus with respect to perfect competition, there are two countervailing effect: optimal quality versus higher quantity. A regulator consequently faces two alternatives: encouraging producers syndication, thereby delegating all production decisions to them, or trying to make the market as competitive as possible to guarantee high quantity levels. In this latter case, the only tool remaining in the hand of a regulator is the lowest quality level that is tolerated, i.e. the setting of a Minimum Quality Standard. We inquire now wether one or the other effect is stronger by comparing W_1 and W_∞. From the

[17] All these measures are given a legal existence in the European common organisation of the market in wine, see Council Regulation No 1493/1999.

[18] In a related model, Sheshinski (1976) studies the monopoly case and shows that distortion can go one way or the other regarding equilibrium quality. However, his model differs on the consumption side, since he assumes a representative consumers and not a continuum of differentiated consumers as we do here.

preceding section, we get:

$$W_1 = \frac{3\theta^*}{8b}\left(a - \frac{c(\theta^*)}{\theta^*}\right)^2$$

and for perfect competition:

$$W_\infty = \frac{\underline{\theta}}{2b}\left(a - \frac{c(\underline{\theta})}{\underline{\theta}}\right)^2$$

On one hand W_∞ goes to 0 when $\underline{\theta}$ goes to zero. On the other hand, when $\underline{\theta} = \theta^*$, comparison of (5a) and (7a) tells us that perfect competition leads production to the socially optimum level. It is easily seen that W_∞ is increasing in $\underline{\theta}$ as soon as $\underline{\theta} \leq \theta^*$. Thus overall we have the following result:

Proposition 3 *There exists some minimum quality threshold $\hat{\theta}$ such that:*

$$W_\infty \geq W_1 \text{ if and only if } \underline{\theta} \geq \hat{\theta}$$

This indicates that the prerequisite for a competitive market to work adequately is the possibility of imposing a minimum quality standard. Whatever the way this is put in place, through norms on production conditions and/or ex-post audit of quality, one first has to go through a regulatory phase for competition to be desirable. In other words, imposing standard and favoring competition are complementary in the present context. The lemma also tells us that for products such as wine, where quality is not perfectly objective and quantifiable, the problem is pervasive whether market forces are a good solution for regulating production.

6 Regulation issues

We know turn to the question of public intervention. As we have seen, unregulated market does not attain the social optimum, so there might be a role for regulation.

6.1 Regulation(s) of a monopoly

In this subsection, we study how a regulator can let a monopoly operate, and regulate it through four tools: quality, quantity, direct price regulation and subsidy, in the spirit of Sheshinski (1976)[19]. Some results parallels that of Spence (1975) and Sheshinski (1976), but it is here possible to go two steps further, by both characterizing optimal regulation

[19] See also Besanko et al. (1987)for a model of discriminating monopoly selling known quality, and Laffont and Tirole (1993) for more recent developments cast in an incentive framework.

patterns and comparing the different instruments. Surprisingly, this task that has not been undertaken in the mentioned papers.

We state the question as an incomplete regulation contract problem. Otherwise, when the regulator is able to command the values of two variable (quantity and quality, or price and quality, for example), he is able to impose the first-best outcome. Therefore we consider that only one regulatory tool can be used at a time. The typical set of constraints will therefore take the form of minimum quantity to be produced, minimum quality or maximal price. As a reference case, it is for example specified in the European Common Market Regulation that sectoral organisations should neither fix prices, nor render unavailable an excessive proportion of the vintage.

(which is quite the opposite from the conclusions reached by)

6.1.1 Quality Regulation

First, one can remark that using minimum quality standard for a monopoly has no value here, because it chooses here the optimal quality. In fact, an effective (but not efficient) quality regulation would be to forbid too high quality[20]. Indeed, imposing a higher than optimal quality would only reduce the quantity, and induce costly over-quality. On the contrary, by imposing not to go beyond some quality threshold, the regulated monopolist would choose higher quantity than in the absence of constraint. However, this is but a very appealing insight in terms of actual regulation.

6.1.2 Quantity Regulation

Assume now that quality is not enforceable (or at a prohibitively high cost) above some relatively low level. Then the regulator can use quantities as a tool. This means that the regulator asks for a quantity, then the monopoly chooses its quality, and the price is determined as before. For any (regulated) production level Q^{**}, the monopoly seeks to maximize $\Pi = \pi_1$ over $\theta = \theta_1$. This yields the first-order condition:

$$c'(\theta^{**}) = a - bQ^{**} \tag{8}$$

Comparing with (5b) and (7b), this indicates that for a given quantity Q such that $Q_1 < Q < \frac{a}{b}$, the corresponding quality produced either to maximize surplus, by a regulated monopoly or by any n-oligopoly are ordered as:

$$c'(\theta_n) = \frac{1}{n}(a - bQ) < c'(\theta^{**}) = a - bQ < c'(\theta^*) = a - \frac{b}{2}Q$$

[20] Sheshinski (1976) also obtains this result.

The second inequality tells us that quantity is not a sufficient tool to restore the first-best situation. Indeed, imposing the right quantity induces the monopoly to choose a too low quality. The first inequality tells us however that it is possible to improve on the competitive situation. Except if Q is set exactly at the monopoly level Q_1, which would be equivalent not to interfere with monopoly incentives, the welfare can be improved on, at least weakly, by imposing a higher production level. The question is whether it can be strictly increased by quantity regulation.

Following the principal-agent literature, we use the first-order approach (see Rogerson, 1985), that consists of replacing the (unique) best action of the monopoly (the agent) in the objective of the regulator (the principal). This is valid here given the one-to-one relationship (8) between Q^{**} and θ^{**}. After substitution in the welfare, the regulator maximizes:

$$\begin{aligned} W^R &= \int_0^{Q^{**}} p(\theta^{**}, Q)dQ - c(\theta^{**})Q^{**} \\ &= \tfrac{1}{b}(a - c'(\theta^{**}))(\tfrac{1}{2}a\theta^{**} + \tfrac{1}{2}\theta^{**}c'(\theta^{**}) - c(\theta^{**})) \end{aligned}$$

Now, we are able to state the following:

Proposition 4 *Even in the absence of any quality standard, a regulator can strictly increase welfare by imposing a minimum quantity to be produced. The drawback is that it induces a quality loss.*

Using a tool on one dimension of the problem (quantity) has clearly an effect on the other dimension (quality). Also, a one-dimensional policy tool is not sufficient to restore the right quality/quantity trade-off. Finally, note that imposing a minimum quantity to be produced is not necessarily easy when production is subject to risk. For example, in the case of wine, harvest are subject to random events so that low quantity may be attributed to bad luck, leading to a moral hazard problem. In such a case, a minimal quantity order may not be credible.

6.1.3 Price Cap

Another way of tackling the problem of too low quantity may be to limit the selling price, say by setting a price cap $\overline{p}$. This should shift the incentives of the monopoly towards more quantity. It is clear that the regulator should set a cap lower than p_1, and that the monopoly then sells exactly at this regulated price. In this case, the monopoly faces a demand $Q(\theta, \overline{p})$, and thus its program boils down to maximizing over θ the following profit:

$$\overline{\pi}(\theta) = (\overline{p} - c(\theta))Q(\theta, \overline{p}) = \frac{1}{b}(\overline{p} - c(\theta))(a - \frac{\overline{p}}{\theta})$$

One easily checks that this is a concave fonction of θ for relevant values of $\overline{p}$, and the equilibrium value is (implicitly) given by the first-order condition:

$$\frac{1}{b\theta^2}\left[\overline{p}^2 + (\theta c'(\theta) - c(\theta))\overline{p} - a\theta^2 c'(\theta)\right] = 0 \tag{9}$$

Following a standard discussion, the relevant question is: Given that imposing a maximal price influences both quality and quantity offered, can price regulation do better that quantity regulation? It happens to be the case that one system uniformly dominates the other, irrespective of the parameters of the model.

Proposition 5 *Price regulation is less efficient than quantity regulation.*

Weiztman (1974) showed that one or the other tool (price or quantity) is better at regulating the production of a firm under uncertainty, depending on the (relative) curvatures of the benefit and cost functions. In Weiztman's model, there is always a one-to-one relationship between price and quantity, while in the present case, given the interplay between quality and quality, the answer is clear-cut: quantity regulation unambiguously dominates price regulation. One should insist on the fact that it is strictly equivalent for a monopoly to choose price and quality or quantity and quality (see for example Spence, 1975). In other words, this result does not rely on an asymmetric strategic effect of price and quantity.

The intuition is as follows. Around the unconstrained monopoly equilibrium, since we have seen that quality is at the socially optimal level, both welfare and monopoly profit have derivatives in quality that are zero. In turn, from a welfare point of view, there is too few quantity, so that the derivative of the welfare with respect to quantity is positive, while, by definition of the monopoly optimal choice, the derivative of monopoly profit is zero. Thus a regulator wants - at least locally - to trade-off quantity against quality. Under price control, the monopoly can exploit the substitution between quality and quantity to attain the regulated price. In turn, with quantity regulation, the trade-off by the monopoly is more constrained towards quantity, which is what a regulator seeks. Stated differently, under quantity control, the monopoly meets the constraint either by lowering the price, or increasing quality, both effects being socially desirable, while under price control, the monopoly meets the constraint either by increasing quantity, which is desirable, or lowering quality, which is not. Therefore quantity control involves a valuable trade-off, while price control does not.

Going back to our wine example, the result may explain that price regulation has been abandoned some fifteen years ago[21], while the use of quantity regulation is still widespread.

[21] Champagne used to regulate the grape prices until 1991, see Gaucher et al., 2005.

Another ever surviving practice is subsidy. We study its effect in the next subsection.

6.1.4 Subsidy

If the regulator sets up a subsidy, say s per unit sold, the profit of the monopoly becomes:

$$\pi_1^s(\theta, Q) = (p(\theta, Q) + s)Q - c(\theta)Q$$

Interestingly, while subsidy and price regulation are both price-based instruments, they operate quite differently. First, the subsidy has no *direct* effect on quality, since the first-order condition is formally unchanged. However, there is an effect on quality through the quantity effect. The first-order conditions are indeed:

$$(a - bQ^s) = c'(\theta^s)$$
$$p(\theta^s, Q^s) - c(\theta) + s = b\theta^s Q^s$$

Proposition 6 *The use of a subsidy degrades the quality offered by a monopoly but increases quantity. Moreover, any outcome reached with a subsidy can be attained with quantity regulation.*

If the subsidy could be made dependent on quality (in which case a minimum quality standard could in fact be used), the regulator would face a procurement problem à la Laffont and Tirole (1993). Of course, in such circumstances it is feasible to attain optimal production, but as remarked, this is because the quality problem would then be trivially solvable.

This proposition expresses that, even absent financing frictions (distortionary tax to finance the subsidy, cost of public funds...), a subsidy - which is a 'price signal' kind of tool - is a more powerful tool than direct price regulation, but not better than quantity regulation (and strictly worse if one accounts for the costs of financing the tool). The only advantage of a subsidy is that financial incentives prevent the moral hazard problem mentioned previously when quantity is a random variable. But except in such a case, price-based instruments are overall less efficient than quantity regulation.

6.2 Competition Policy in oligopoly

The effect of price regulation and subsidy in oligopoly is qualitatively similar to that for the monopoly case, so that it is left apart in this section. However quantity regulation takes

scale=1]fig3.pdf

Figure 3: Regulatory instruments

a different form here. The question we ask in this paragraph can be expressed as follows: Is it possible, and if so when, to increase quality without lowering too much quantity in an oligopoly situation? In fact we will show that imposing quotas[22] can be a desirable competition policy.

Proposition 7 *Assume c is quadratic. If the minimum quality standard constraint is not binding in absence of regulation, then there exists an optimal uniform quota system that is strictly welfare improving for any $n \geq 2$.*

The last proposition gives a rationale for the use of quotas on some agricultural market: it may enhance quality more than it decreases quality. This is true especially when the quality standard is hard to specify or enforce, like it is admittedly most often the case in wine.

To conclude this section on regulation, figure 3 presents a synthetic view of the salient regulations patterns.

The dotted line represents iso-welfare curves. The picture is drawn for quadratic costs of quality, which implies a linear relationship between quality and quantity for a monopoly regulated in quantity. The dot on this line represents the optimal policy when using quantity regulation with a single firm. Typically, the locus of price regulation for a monopoly is a curve below that of quantity regulation. Also, the standard is assumed to be zero (the effect of the standard is pictured on figure 2.

7 Conclusion

This paper studies the interplay of quality and quantity in a Cournot setting. A pervasive trade-off between quantity and quality arises on such markets for experience goods. Under the suggested assumption that consumers only know the average quality of the good produced by many producers, market structure allows either high quality and low quantity (small numbers of competitors), or low quality and high quantity (large number of competitors).

[22] A typical example is the maximal yield per surface in effect for European wines.

Consumers' surplus and welfare are shown to be convex in the number of producers.
This implies that entry regulation can be beneficial and that one of the extreme market structure is optimal absent other regulatory tools. This sheds light on the role - and legal existence - of producers organisations, acting as monopoly. These are generally fought by competition authority as cartels, except in agricultural market and some professions like lawyers and doctors, the rationale put forward being that self-regulation and some quantity regulation allows to adjust towards more quality.
We also studied the effectiveness of various regulatory tools. Typically, minimum quality standards and entry favoring policy are complementary policy instruments. Competition is harmful when standards are difficult to implement (as in the wine industry, but also in highly specialized jobs), whereas classical efficiency results obtain for high standards (or complete information) when the number of competitors tends to infinity. We study in details the regulation of a monopoly, and also demonstrate that in oligopoly quotas may improve welfare. Quantity-base regulation overall performs better than price-based regulation.
Several extensions of the model are left for further research, such as incorporating retailing, modeling explicitly the quality enforcement procedure, by an external authority or within the syndicate, and taking into account heterogeneity among the producers and the structure of collective decision making within the organisation. Other valuable extension could consider opening markets, where entry can occur once a group is already formed.

A Appendix: Omitted Proofs

A.1 Proof of Lemma 1

As a first step, we study the function $\frac{c(\theta)}{\theta}$. It is well defined for any $\theta \geq 0$ because $c(\theta) \underset{\theta \to 0^+}{\sim} \theta c'(\theta)$ and $c'(0) = 0$, thus $\underset{\theta \to 0^+}{lim} \frac{c(\theta)}{\theta} = 0$. Consider now $f(\theta) = c'(\theta)\theta - c(\theta)$. Its derivative is $c''(\theta)\theta$, so it is increasing, and $f(0) = 0$, thus f is always positive. This indicates on the one hand that:

$$\frac{c(\theta)}{\theta} \text{ is increasing} \tag{10}$$

and on the other hand that:

$$\frac{c(\theta)}{\theta} \leq c'(\theta) \text{ for any } \theta \tag{11}$$

Note that if $c''' \geq 0$, given that $c'(0) = 0$, we also obtain that $\theta c''(\theta) \geq c'(\theta)$ by the same token. Consider now the function $g(\theta) = c'(\theta) - \frac{c(\theta)}{\theta}$ for $\theta > 0$. Its derivative is $g'(\theta) = \frac{1}{\theta^2}(\theta^2 c''(\theta) - \theta c'(\theta) + c(\theta) > \frac{1}{\theta}(\theta c''(\theta) - c'(\theta)) \geq 0$, using the preceding result. Thus g is increasing and positive. By rewriting (5b), θ^* must solve:

$$a - c'(\theta) = c'(\theta) - \frac{c(\theta)}{\theta}$$

From the assumption $c'(\underline{\theta}) < \frac{a}{2}$, the left hand side is bigger than $\frac{a}{2}$ for $\theta = \underline{\theta}$, while the right hand side is strictly smaller than $\frac{a}{2}$ for $\theta = \underline{\theta}$. Also, since $c'' > 0$ and $c''' \geq 0$, the LHS decreases to minus infinity while the RHS is increasing. Thus there exists exactly one θ^* solving (5b). Finally, since $\frac{c(\theta^*)}{\theta^*} \leq c'(\theta^*) \leq \frac{a}{2}$, equation (5a) yields a positive optimal quantity.

A.2 Proof of Proposition 1

The proof uses a number of lemmata. The strategy is to characterize potential equilibria, and check in the end that they indeed exist.

Lemma 2 *There do not exist degenerate equilibria (with some firm producing nothing).*

Proof. First, notice that if all other firms produces nothing, a firm chooses to produce a positive quantity. Suppose now that in equilibrium, some firm i produces a quantity $q_i = 0$, while some other produces $q_j > 0$. Then, it must be the case that the price at $q_i = 0$ is smaller than the marginal cost even for $\theta_i = \underline{\theta}$:

$$\theta(a - bQ) \leq c(\underline{\theta})$$

But an active firm has to make a positive profit, so that $\theta(a-bQ)q_j \geq c(\theta_j)q_j$, and since $q_j > 0$, this means:

$$\theta(a-bQ) \geq c(\theta_j)$$

Also, one has $\theta_j \geq \underline{\theta}$. Combining with the condition for firm i produces nothing implies that necessarily $\theta = \underline{\theta} = \theta_j$. But then the derivative of π_j with respect to q_j writes $\underline{\theta}(a - bQ) - c(\underline{\theta}) = \theta(a-bQ) - c(\theta) = b\theta q_j > 0$, a contradiction. All firms thus have to produce a positive quantity in equilibrium as soon as one of them produces a nonzero quantity, and the first remark allows to conclude. ■

Lemma 3 *If an interior equilibrium exists, it is symmetric.*

Proof. We reason by necessary conditions, assuming that there exists an interior equilibrium with average quality θ and total quantity Q. Consider firm i. Since we consider a putative interior point, the profit π_i has to be locally concave, in particular the necessary first-order conditions have to be satisfied. Substituting the value of q_i from the second FOC in the first FOC yields the necessary condition:

$$\begin{aligned} F(\theta_i) \equiv& (\theta_i - \theta)c'(\theta_i) - \theta\frac{bQ}{a-bQ}c'(\theta_i) + p(\theta, Q) - c(\theta_i) = 0 \\ =& (\theta_i - \theta\frac{a}{a-bQ})c'(\theta_i) + \underbrace{p(\theta, Q) - c(\theta_i)}_{\text{unit margin of firm } i} \end{aligned}$$

All firms produce positive quantities, thus the unit margin of any firm in equilibrium has to be nonnegative. Therefore, the first term has to be nonpositive for $F(\theta_i) = 0$, so that necessarily:

$$\theta_i \leq \theta\frac{a}{a-bQ} \tag{12}$$

Next, consider F as a function of θ_i for the given equilibrium values θ and Q. To be consistent with them, θ_i has to satisfy $F(\theta_i) = 0$. The derivative of F is:

$$F'(x) = (x - \theta\frac{a}{a-bQ})c''(x)$$

Therefore, for $x \leq \theta\frac{a}{a-bQ}$, F is a decreasing function. Also, $F(0) = p(\theta, Q) \geq 0$. Thus $F(x) = 0$ has at most one solution in the relevant range. In other words, there is at most one value of θ_i that is consistent with given equilibrium values (θ, Q). Moreover, this unique solution depends only on the aggregate equilibrium values, and that for any i. We conclude that in any interior equilibrium, $\theta_i = \theta_j$ for any (i, j). It is then straightforward to show that $q_i = q_j$ for any (i, j). ■

Lemma 4 *If one firm chooses the lowest quality in equilibrium, then all firms do so.*

Proof. We have seen that there do not exist degenerate equilibria, so that a constraint $q_i \geq 0$ can not bind. In turn, it may be the case that a constraint $\theta_i \geq \underline{\theta}$ is binding. Consider some equilibrium values (θ, Q). Using the same argument as in the previous lemma, there is at most one interior quality consistent with these values. Thus in equilibrium, there can be at most two quality chosen by the firms, $\underline{\theta}$ and some other (interior) quality $\tilde{\theta}$. Of course, one has $\underline{\theta} \leq \theta \leq \tilde{\theta}$. Let $\underline{q}$ and $\tilde{q}$ be the associated quantities. For the firms choosing $\tilde{\theta}$, both FOCs must be met, while for the ones choosing $\underline{\theta}$, it must be the case that:

$$c'(\underline{\theta}) \geq \frac{\underline{q}}{Q}(a - bQ) \tag{13}$$

That is, they should not want to increase their quality level beyond the lowest one. Now, since both FOCs for $\underline{q}$ and $\tilde{q}$ hold, we obtain:

$$\frac{\tilde{\theta} - \theta}{Q}(a - bQ)\tilde{q} - b\theta\tilde{q} - c(\tilde{\theta}) = \frac{\underline{\theta} - \theta}{Q}(a - bQ)\underline{q} - b\theta\underline{q} - c(\underline{\theta})$$

Substituting the FOC for $\tilde{\theta}$ and using (13) yields the next inequality (observe that the coefficient of $\underline{q}$ is negative in the last equation):

$$(\tilde{\theta} - \theta)c'(\tilde{\theta}) - \frac{b\theta c'(\tilde{\theta})}{a - bQ} - c(\tilde{\theta}) \geq (\underline{\theta} - \theta)c'(\underline{\theta}) - \frac{b\theta c'(\underline{\theta})}{a - bQ} - c(\underline{\theta})$$

or, after rearranging:

$$\tilde{\theta}c'(\tilde{\theta}) - \underline{\theta}c'(\underline{\theta}) - c(\tilde{\theta}) + c(\underline{\theta}) \geq \frac{a\theta}{a - bQ}(c'(\tilde{\theta}) - c'(\underline{\theta}))$$

But we have seen that an interior solution - here, $\tilde{\theta}$ - must satisfy (12), so that $\frac{a\theta}{a-bQ} \geq \tilde{\theta}$. Using this fact in the last inequality yields:

$$\tilde{\theta}c'(\underline{\theta}) - c(\tilde{\theta}) \geq \underline{\theta}c'(\underline{\theta}) - c(\underline{\theta})$$

The right-hand side and left-hand side are equal for $\tilde{\theta} = \underline{\theta}$. But the left-hand side is a decreasing function of $\tilde{\theta}$, since its derivative w.r.t. $\tilde{\theta}$ is $c'(\underline{\theta}) - c'(\tilde{\theta}) \leq 0$. Therefore the inequality can only be satisfied with equality, i.e. for $\tilde{\theta} = \underline{\theta}$. ■

Combining the last two lemmata tells us that any candidate equilibrium is symmetric. Indeed, either it is interior and symmetric by lemma 3, or all firms choose the lowest quality level, by lemma 4, in which case it is easily shown by standard considerations that they also choose the same quantity (for example, Theorem 2.3 in Amir and Lambson (2000) apply since we can consider the game for fixed quality and marginal costs).

Now we want to check whether both types of candidate equilibria indeed exist, and whether they can coexist. We first show the latter. Consider the candidate interior equilibrium. Using symmetry and combining the two FOCs yields immediately:

$$Q_n = \frac{n}{(n+1)b}(a - \frac{c(\theta_n)}{\theta_n})$$
$$c'(\theta_n) = \frac{1}{n+1}(\frac{a}{n} + \frac{c(\theta_n)}{\theta_n}) \tag{14}$$

where we use the subscript n to denote an equilibrium value with n competitors. It is necessary for such an interior equilibria to exists that the second equation has as solution θ_n higher than $\underline{\theta}$.

Lemma 5 *Both candidate equilibria can not coexist.*

Proof. The equilibrium with $\theta_i = \underline{\theta}$ exists if and only if the FOC in q_i is satisfied while (13) holds. In a symmetric equilibrium, these conditions write:

$$Q = \frac{n}{(n+1)b}(a - \frac{c(\underline{\theta})}{\underline{\theta}})$$
$$c'(\underline{\theta}) \geq \frac{1}{n+1}(\frac{a}{n} + \frac{c(\underline{\theta})}{\underline{\theta}}) \tag{15}$$

Where we have substituted the expression of Q in the inequality. But note that for a given n, (14) and (15) together imply $c'(\theta_n) \leq c'(\underline{\theta})$, which in turn implies $\theta_n \leq \underline{\theta}$. Therefore, both equilibria can not coexist. When the solution to (14) satisfies $\theta_n \geq \underline{\theta}$, only the interior equilibrium can exist, while when $\theta_n \leq \underline{\theta}$, only the corner equilibrium can exist. ■

We now characterize the unique equilibrium values. To prove *(i)*, we begin by finding lower and upper bounds for $c'(\theta_n)$ when (6) holds (i.e. when the solution to the market equilibrium is interior in θ_n). We have immediately that $c'(\theta_n) \geq \frac{a}{n(n+1)}$. Moreover, we have seen that $\frac{c(\theta)}{\theta} \leq c'(\theta)$, thus $c'(\theta_n) \leq \frac{1}{n+1}(\frac{a}{n} + c'(\theta_n))$, which yields $c'(\theta_n) \leq \frac{a}{n^2}$. We have overall:

$$\frac{a}{n(n+1)} \leq c'(\theta_n) \leq \frac{a}{n^2} \tag{16}$$

from which we deduce:

$$c'(\theta_{n+1}) \leq \frac{a}{(n+1)^2} \leq \frac{a}{n(n+1)} \leq c'(\theta_n) \tag{17}$$

Also, after some $N(\underline{\theta})$, $\theta_n = \underline{\theta}$ for all $n \geq N(\underline{\theta})$. Indeed, if (7b) yields a quality smaller than the lowest possible one, this constraint is binding, and it is the only one. Quantity is then determined by the other FOC, with $\theta_n = \underline{\theta}$. Point *(ii)* is simply the limit case.

We now prove *(iii)*. We saw that $\frac{c(\theta)}{\theta}$ is increasing. Thus, given that θ_n is decreasing, Q_n is increasing. The limit result *(iv)* simply follows from the fact that in the limit $\theta_\infty = \underline{\theta}$ and that $\frac{c(\theta_\infty)}{\theta_\infty}$ is then smaller than $\frac{c(\theta^*)}{\theta^*}$, comparing with the optimal quantity in (5a) ends the characterization.

To end the proof, there remains now to check that π_i is locally concave at the putative interior equilibrium, so that it indeed constitute an equilibrium. Simple, although tedious, calculations yield the following second order derivatives for the profit of firm i:

$$\begin{aligned}
\frac{\partial^2 \pi_i}{\partial q_i^2} &= -2\left(b\theta + (\theta - \theta_i)(a - bQ)\frac{Q - q_i}{Q^2}\right) \\
\frac{\partial^2 \pi_i}{\partial \theta_i^2} &= -c''(\theta_i) q_i \\
\frac{\partial^2 \pi_i}{\partial q_i \partial \theta_i} &= \left(a\frac{Q - q_i}{Q^2} - b\right) q_i + \frac{a - bQ}{Q} q_i - c'(\theta_i)
\end{aligned}$$

Substituting the first-order conditions at the interior equilibrium, $q_i = \frac{Q_n}{n}$ and $\theta_i = \theta_n$ yields:

$$\begin{aligned}
\frac{\partial^2 \pi_i}{\partial q_i^2} &= -2b\theta_n \\
\frac{\partial^2 \pi_i}{\partial \theta_i^2} &= -c''(\theta_n)\frac{Q_n}{n} \\
\frac{\partial^2 \pi_i}{\partial q_i \partial \theta_i} &= c'(\theta_n) - \frac{a}{n^2}
\end{aligned}$$

Now, the determinant of the Hessian matrix of π_i is:

$$det\, H_i = \frac{\partial^2 \pi_i}{\partial q_i^2}\frac{\partial^2 \pi_i}{\partial \theta_i^2} - \left(\frac{\partial^2 \pi_i}{\partial q_i \partial \theta_i}\right)^2 = 2b\frac{Q_n}{n}\theta c''(\theta_n) - \left(c'(\theta_n) - \frac{a}{n^2}\right)^2$$

From the FOC in θ_i, we have $bQ_n = a - nc'(\theta_n)$, we know that $\theta c''(\theta) \geq c'(\theta)$ for all θ from the proof of lemma 1 and finally we just obtained that $\frac{a}{n(n+1)} \leq c'(\theta_n) \leq \frac{a}{n^2}$. Substituting step-by-step in the Hessian determinant yields:

$$\begin{aligned} det\, H_i &= 2(\frac{a}{n} - c'(\theta_n))\theta_n c''(\theta_n) - \left(c'(\theta_n) - \frac{a}{n^2}\right)^2 \\ &\geq 2(\frac{a}{n} - c'(\theta_n))c'(\theta_n) - \left(c'(\theta_n) - \frac{a}{n^2}\right)^2 \\ &\geq 2\frac{(n-1)a}{n^2}\frac{a}{n(n+1)} - \left(\frac{a}{n^2(n+1)}\right)^2 \\ &\geq \frac{(2n(n-1)(n+1)-1)a^2}{n^4(n+1)^2} > 0 \text{ for } n \geq 2 \end{aligned}$$

The case of monopoly ($n = 1$) is easily handled separately, in a way similar to the proof of lemma 1. The interior equilibrium therefore exists for any n when the quality standard is not binding.

A.3 Proof of proposition 2 (consumers' welfare)

We first consider the case where $n < N(\underline{\theta})$. The difference between U_{n+1} and U_n satisfies:

$$\begin{aligned} 2b(U_{n+1} - U_n) &= \theta_{n+1}(a - (n+1)c'(\theta_{n+1})^2 - \theta_n(a - nc'(\theta_n)^2) \\ &\leq \theta_{n+1}(a - (n+1)\tfrac{a}{(n+1)^2})^2 - \theta_n(a - n\tfrac{a}{n(n+1)}) \\ &\leq (\theta_{n+1} - \theta_n)(a - \tfrac{a}{n+1})^2 \\ &< 0 \end{aligned}$$

where the first inequality obtains using the preliminary result obtained in the proof of lemma 1, applied to $c'(\theta_n)$ and $c'(\theta_{n+1})$. Now consider the case where $n \geq N(\underline{\theta})$: Quantity is strictly increasing in n while quality remains constantly at the minimum level, thus consumers surplus is strictly increasing.

A.4 Proof of proposition 4 (quantity regulation of a monopoly)

First we calculate the welfare as a function of the best-response of the agent in term of quality (θ^{**}) to an ordered quantity Q^{**}:

$$\begin{aligned} W^{**}(\theta^{**}) &= \textstyle\int_0^{Q^{**}} p(\theta^{**}, Q)dQ - c(\theta^{**})Q^{**} \\ &= Q^{**}\left(\theta^{**}(a - \tfrac{1}{2}bQ^{**}) - c(\theta^{**})\right) \\ &= \tfrac{1}{b}(a - c'(\theta^{**}))(\tfrac{1}{2}a\theta^{**} + \tfrac{1}{2}\theta^{**}c'(\theta^{**}) - c(\theta^{**})) \end{aligned}$$

Thus the derivative of the welfare under quantity regulation of a monopoly is:

$$\begin{aligned} b\tfrac{dW^{**}}{d\theta^{**}} &= -c''(\theta^{**})(\tfrac{1}{2}a\theta^{**} + \tfrac{1}{2}\theta^{**}c'(\theta^{**}) - c(\theta^{**})) + (a - c'(\theta^{**}))(\tfrac{1}{2}a + \tfrac{1}{2}\theta^{**}c''(\theta^{**}) - \tfrac{1}{2}c'(\theta^{**})) \\ &= \tfrac{1}{2}(a - c'(\theta^{**}))^2 + c''(\theta^{**})(c(\theta^{**}) - \theta^{**}c'(\theta^{**})) \end{aligned}$$

The second derivative is:

$$b\frac{d^2W^{**}}{d\theta^{**2}} \quad = \theta^{**}c'''(\theta^{**})(c(\theta^{**}) - \theta^{**}c'(\theta^{**})) - c''(\theta^{**})(a - c'(\theta^{**}) + \theta^{**}c''(\theta^{**}))$$

Given the assumption that $c''' \geq 0$, and using the preliminary we see that W^{**} is strictly concave. There is thus a unique θ^{**} that maximizes W^{**}.

To end the proof, we prove now that it is strictly smaller than $\theta^* = \theta_1$. Consider the derivative of W^{**} at θ^*; we know from (5b) that $c'(\theta^*) = \frac{1}{2}(a + \frac{c(\theta^*)}{\theta^*})$, and we obtain by replacing in the derivative:

$$\begin{aligned} b\frac{dW^{**}}{d\theta^{**}}(\theta^*) \quad &= \tfrac{1}{2}\left((a - c'(\theta^*))^2 - \theta^*c''(\theta^*)(a - \tfrac{c(\theta^*)}{\theta^*})\right) \\ &\leq \tfrac{1}{2}\left((a - c'(\theta^*))^2 - \theta^*c''(\theta^*)(a - c'(\theta^*)\right) \\ &\leq \tfrac{1}{2}(a - c'(\theta^*))(a - 2c'(\theta^*)) \\ &\leq -\tfrac{1}{2}\tfrac{c(\theta^*)}{\theta^*}(a - c'(\theta^*)) < 0 \end{aligned}$$

where the first inequality uses the preliminary for c', the second inequality uses the preliminary for c'' and the last comes from using again (5b).

This means that $\frac{dW^{**}}{d\theta^{**}}$ vanishes for a θ^{**} strictly smaller than $\theta^* = \theta_1$. The unique solution being interior, it is necessarily strictly better than the non-regulated monopoly.

A.5 Proof of proposition 5 (price regulation of a monopoly)

The unique positive root of the polynom (9) in $\overline{p}$ is:

$$\overline{p} = \frac{1}{2}\left((c(\theta) - \theta c'(\theta)) + \sqrt{(\theta c'(\theta) - c(\theta))^2 + 4a\theta^2 c'(\theta)}\right)$$

which defines implicitly the unique best-response of the monopoly in term of quality. Let $B(\theta) = (c'(\theta) - \frac{c(\theta)}{\theta})^2 + 4ac'(\theta)$. Then:

$$\overline{p} = \frac{1}{2}\left(c(\theta) - \theta c'(\theta) + \theta\sqrt{B(\theta)}\right)$$

Because the demand is $Q = \frac{1}{b}(a - \frac{\overline{p}}{\theta})$, the corresponding quantity sold is:

$$Q = \frac{1}{b}\left(a - c'(\theta) + \frac{1}{2}\left(3c'(\theta) - \frac{c(\theta)}{\theta} - \sqrt{B(\theta)}\right)\right)$$

In the case of quantity regulation, from (8), for any regulated quantity Q,we had the relationship:

$$Q = \frac{1}{b}(a - c'(\theta))$$

It is possible to do better than quantity regulation if and only if for some best-response quality level, the quantity produced under price regulation is greater than that under quantity regulation, thus if and only if $D(\theta) = 3c'(\theta) - \frac{c(\theta)}{\theta} - \sqrt{B(\theta)}$ is positive (for relevant values of $\overline{p}$). Comparison of $B(\theta)$ and $(3c'(\theta) - \frac{c(\theta)}{\theta})^2$ tells us that $D(\theta)$ is positive if and only if:

$$2c'(\theta) - \frac{c(\theta)}{\theta} \geq a$$

we have already seen that $c'(\theta) - \frac{c(\theta)}{\theta}$ is increasing, thus $2c'(\theta) - \frac{c(\theta)}{\theta}$ is also increasing. But from (5b), we know $c'(\theta^*) = \frac{1}{2}(a + \frac{c(\theta^*)}{\theta^*})$, thus $D(\theta^*) = 0$, and $D(\theta) < 0$ for $\theta < \theta^*$. This means that price regulation can do better than quantity regulation only if $\overline{p}$ is greater than the monopoly price. But this is absurd, thus price regulation can never do better than quantity regulation.

A.6 Proof of proposition 6 (subsidized monopoly)

Combining the unregulated monopoly first-order conditions with that of the subsidized monopoly yields the following relationships:

$$\begin{cases} c'(\theta^s) - c'(\theta_1) = b(Q_1 - Q^s) \\ \left(c'(\theta^s) - \frac{c(\theta^s)}{\theta^s}\right) - \left(c'(\theta_1) - \frac{c(\theta_1)}{\theta_1}\right) - b(Q^s - Q_1) = -\frac{s}{\theta^s} \end{cases}$$

Since $c'(\theta) - c(\theta)/\theta$ is an increasing function of θ (see the proof of lemma 1), these equations implies:

$$\theta^s \leq \theta_1 \text{ and } Q^s \geq Q_1$$

which proves the first assertion.
Now, since along a quantity regulation we have the first-order condition:

$$c'(\theta) = a - bQ$$

it is possible to replicate any pair (Q^s, θ^s) with quantity regulation simply by choosing directly $Q = Q^s$ since the first-order conditions in θ coincide.

A.7 Proof of proposition 7 (quotas in oligopoly)

Consider uniform quotas ($q_i = \frac{Q}{n}$), assumed to be constraining, otherwise the situation is unchanged . When firms are quantity constrained, the equilibrium is uniquely defined and is symmetric in quality, from standard arguments similar to that already given in the proof

of proposition 1. Therefore, we compare two well defined situation: the unconstrained equilibrium, in which firms choose freely quality and quantity (and $\theta_n > \underline{\theta}$) and the equilibrium in which the quota constrains the quantity choice.
For any (Q, θ), the expression of welfare is:

$$W = Q\left[\theta(a - \frac{1}{2}bQ) - c(\theta)\right]$$

So that when Q is the variable decision and θ is the result of the constrained equilibrium, we obtain easily:

$$\frac{dW}{dQ} = p(\theta_n^Q, Q) - c(\theta_n^Q) + Q\left[(a - \frac{1}{2}bQ) - c'(\theta_n^Q)\right]\frac{d\theta_n^Q}{dQ}$$

In the quota equilibrium, the (uniform) quality θ_n^Q is given by the only relevant first-order condition, which is valid for any Q and differentiable, so that we have the relationships:

$$c'(\theta_n^Q) = \frac{1}{n}(a - bQ) \qquad \text{and} \qquad \frac{d\theta_n^Q}{dQ} = \frac{-b}{nc''(\theta_n^Q)}$$

Substituting in the derivative of the welfare yields:

$$\frac{dW}{dQ} = p(\theta_n^Q, Q) - c(\theta_n^Q) - \frac{bQ}{n^2c''(\theta_n^Q)}\left[a + (n-2)(a - \frac{1}{2}bQ)\right]$$

Now, we have seen in proposition 1 that the unconstrained equilibrium is symmetric, so that from the FOC for quantity we have the relationship:

$$p(\theta_n, Q_n) - c(\theta_n) = \frac{b\theta_n Q_n}{n}$$

When the quota is set exactly at the value $Q = Q_n$, we have $\theta_n = \theta_n^Q$, and we can substitute the preceding relationship in the derivative of the welfare to obtain:

$$\left.\frac{dW}{dQ}\right|_{Q=Q_n} = \frac{bQ_n}{n^2c''(\theta_n)}\left(n\theta_n c''(\theta_n) - \left[a + (n-2)(a - \frac{1}{2}bQ_n)\right]\right)$$

If c is quadratic, $\theta c''(\theta) = c'(\theta)$ for any θ. From the proof of proposition 1, we know that $c'(\theta_n) \leq \frac{a}{n^2}$. Therefore we have for $n \geq 2$:

$$\left.\frac{dW}{dQ}\right|_{Q=Q_n} \leq \frac{bQ_n}{n^2c''(\theta_n)}\left(-\frac{n-1}{n}a - (n-2)(a - \frac{1}{2}bQ_n)\right) < 0$$

Overall, since $W(Q = 0) = 0$, W is decreasing at Q_n and $[0, Q_n]$ is a compact interval, there exists an optimal constraining quota.

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