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by Svend Albæk
and Per Baltzer Overgaard

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Svend Albæk
CentER, Tilburg University

and

Per Baltzer Overgaard
Institute of Economics, University of Aarhus

Abstract:

This paper considers a vertical manufacturer-retailer interaction in a context of asymmetric information. The monopolist manufacturer is privately informed about the intensity of consumer demand which may be high or low. In addition to the state of nature, consumer demand responds to the retail price and advertising by the manufacturer. The vertical interaction is modelled as a signalling game, in which the manufacturer initially sets a wholesale price and a level of advertising. The retailer infers information from the observable choices of the manufacturer and responds by setting a retail price. By refining retailer inferences, we show that the game has a *unique* equilibrium outcome where all information is revealed by the manufacturer's choices. When consumer demand is high, the manufacturer chooses the full-information pair of wholesale-price and advertising. In contrast, to induce the right beliefs, the low-demand manufacturer is forced to distort the price-advertising pair by behaving as if demand is even lower. As a consequence, the wholesale price is distorted downward, whereas demand-enhancing advertising may be distorted in either direction. Dissipative advertising is not distorted since it is never used.

Key words: Manufacturer-Retailer Relations, Demand Uncertainty, Signalling, Wholesale Pricing and Advertising, Equilibrium Refinements.

JEL: C72, D82, L12

1. Introduction

Vertical interactions between manufacturers and retailers often take place against a background of asymmetric information about final demand. In the setting of this paper we assume that for some exogenous (e.g. legal) reason a monopolist manufacturer is prevented from integrating forward into retailing but is forced to operate through a network of geographically dispersed retailers with local monopolies. Geographic dispersion is modelled very simply by assuming that consumers in one region are prevented by distance from making their purchases in another region. Market demand in each region is affected by economy-wide shocks, and we assume that the manufacturer has obtained complete and perfect information about demand intensity during market research. Local retail monopolists, on the other hand, are incompletely informed about the state of demand.

We focus on the following simple setting. Since regional retail markets are independent we analyse a representative market in this paper.[1] Assume that demand intensity is either high or low, and that the manufacturer is privately informed about the actual intensity. It follows that the retailer will attempt to infer information from the observable actions of the informed manufacturer in order to set the level of its choice variables optimally. We shall assume that the choice variable of the retailer is the retail price, whereas, the manufacturer chooses a wholesale price and (possibly) a positive level of advertising. Final consumer demand depends on the state of nature, the retail price and level of advertising.

At a formal level, we model the following sequence of moves. Before any market interactions take place nature chooses the intensity of consumer demand, and the manufacturer is fully informed about nature's choice. Next, the manufacturer sets a wholesale price and a level of advertising, and both are fully observed by the retailer. The retailer does not, however, observe nature's choice, but attempts to infer information from the observable actions of the manufacturer. Then, the retailer sets a retail price on the basis of its (possibly updated) beliefs about demand. Finally, the retailer (and, hence, the manufacturer) serves whatever demand is forthcoming at the posted price. The sequence of moves modelled constitutes a signalling game and we invoke refinements of sequential equilibrium to select outcomes. Formal definitions follow Kreps and Wilson (1982) and Cho and Kreps (1987).

The purpose of this paper is to investigate the extent to which the choice variables of the informed manufacturer are distorted compared to the case of full retailer information. Now, there are two *types* of manufacturers distinguished by their observations of actual demand, and we will refer to them as the high-demand type and the low-demand type. From the case of full information we can easily conclude that (subject to assumptions about the cost functions) a manufacturer has an interest in selling as many units as possible. So, it is in the interest of the manufacturer that the retailer charges a low retail price. Consequently, when we move to an asymmetric information structure, *both* types of the manufacturer have an incentive to *signal* that actual demand is low since this induces the retailer to charge a low price. Hence, the retailer and a low-demand manufacturer are confronted with an adverse selection problem. To alleviate this problem and allow a correct retailer inference, the low-demand manufacturer is forced to choose a combination of wholesale price and advertising level that it does not pay the high-demand manufacturer to copy. Otherwise manufacturer strategies are non-revealing and the two types are pooled.

The signalling game considered generally has a multiplicity of equilibrium outcomes supported by either separating or pooling equilibrium strategies. But, once we rule out equilibrium dominated strategies in the sense of Cho and Kreps (1987), we conclude that a *unique* separating outcome remains. At this equilibrium outcome, the high-demand manufacturer reverts to the full-information combination of wholesale price and advertising. The low-demand manufacturer, on the other hand, chooses its signals so as to induce a demand-reducing distortion (in the terminology of Bagwell and Ramey (1990)). By a demand-reducing distortion is understood that the low-demand manufacturer chooses the optimal pair of wholesale price and advertising of a hypothetical manufacturer with even lower demand when retailers react as if demand is at the actual level (i.e. low). We show that this implies a *downward* distortion in the wholesale price whereas directly demand-enhancing advertising may be distorted in either direction. However, if advertising is purely dissipative (as in Milgrom and Roberts (1986)) its level is set to zero, and, hence, is *not distorted*.

The analysis in this paper is related to the rapidly expanding literature on signalling in economics originating in the Spence-model (see the seminal paper by Spence (1973) and the game theoretic treatment by Kreps (1984)). Of particular interest are the papers of Milgrom and Roberts on limit-pricing by a privately informed incumbent in response to potential entry (Milgrom and Roberts, 1982) and on price and advertising as signals of product quality (Milgrom and Roberts, 1986). These papers introduce various refinements to select equilibria that point to a unique separating equilibrium outcome (when separating equilibria exist). The qualitative features of the market distortions resulting from private information are very similar to those spelled out above. Most closely related to the present paper are two papers by Bagwell and Ramey (1988, 1990) that extend the Milgrom and Roberts (1982) analysis of limit pricing.

Bagwell and Ramey (1988) consider the role of pre-entry price and advertising in signalling whether incumbent-costs are low or high. They conclude that the price-advertising pair of a low-cost incumbent constitutes a cost-reducing distortion. They show that at most one separating outcome as well as a continuum of outcomes where the different types of the incumbent are pooled survive the equilibrium refinements of Cho and Kreps (1987). This contrasts the present analysis where separation is always possible and all pooling equilibria are destabilized. Pooling equilibria survive in Bagwell and Ramey (1988) because the uninformed player's response is a map from beliefs into a dichotomous entry choice, which allows the informed player to provoke its unique preferred response (i.e. non-entry) even in a pooling equilibrium. In the present paper such a preferred response is ruled out under pooling, and this establishes a unique separating outcome.

Bagwell and Ramey (1990) develop a model of entry deterrence (or accommodation) when the competitors of the incumbent are incompletely informed about consumer demand. In structure their model is very similar to the vertical game considered in this paper, in the sense that the response map of the uninformed player is smooth, and the qualitative results correspond. In one version of their model the incumbent has incentives to signal low demand to ensure entry on a small scale.[2] The incumbent uses the pre-entry price and advertising level as signals, and Bagwell and Ramey conclude that a low-demand incumbent chooses signals to induce a demand-reducing distortion. As a consequence, the pre-entry price is distorted downward (viz. "limit-pricing") whereas advertising may be distorted in either direction.[3]

The outline of the paper is as follows. Section 2 formalizes the vertical interaction. Then, in section 3 the set of separating equilibria is analysed. Finally, we turn to pooling equilibria in section 4. A few concluding remarks are contained in section 5. Proofs are in the appendix.

2. The Model

As outlined in the introduction the monopolist manufacturer supplies his product to a monopolist retailer, who in turn serves the demand of an anonymous mass of price taking final consumers. We assume that the final consumer demand is of the form α^i

+ x(p,A) where $i \in \{L,H\}$, and $\alpha^L < \alpha^H$. We refer to demand as being low or high. The retail price $p \in \mathbf{R}_+$ is chosen by the retailer while the manufacturer chooses the level of advertising $A \in \mathbf{R}_+$. x(p,A) is assumed to be continuous, strictly decreasing in p, and non-decreasing in A. We allow for the possibility that advertising is dissipative, that is, that A has no effect on demand. Besides A the manufacturer chooses a wholesale price $w \in \mathbf{R}_+$. Thus we assume that the manufacturer has all bargaining power, since the retailer has no say in determining w. To economize on notation unit costs of production and retailing are set to zero while the cost of advertising is simply A.[4] The profit to the retailer is then $(p-w)[\alpha^i + x(p,A)]$ while the profit to the type i manufacturer is $w[\alpha^i + x(p,A)] - A$.

The crucial assumption concerning the structure of information in this paper is that before any market interaction takes place, the manufacturer obtains complete and perfect information about the value of the shift parameter α^i, whereas the retailer remains uninformed about the realization of α^i. The retailer's prior probability assessment about the value of α^i is specified as $\mathrm{Prob}(\alpha^H) = \rho^*$ and $\mathrm{Prob}(\alpha^L) = 1 - \rho^*$, $\rho^* \in (0,1)$. We assume that ρ^* is common knowledge. After observing the manufacturer's wholesale and advertising choice (w,A) the retailer forms a posterior belief $\rho(w,A) \in [0,1]$ about the probability that demand is high. Using this belief the retailer then maximizes expected profit (both manufacturer and retailer are risk neutral), that is, he solves the problem

$$\max\ \rho(p-w)[\alpha^H+x(p,A)] + (1-\rho)(p-w)[\alpha^L+x(p,A)]$$

with respect to p. We assume that this problem has a unique solution which we call $p(w,A,\rho)$, $p > w$. It is easy to show that this function is strictly increasing in both w and ρ. We furthermore assume it to be continuous in all arguments.

Throughout the paper we shall restrict attention to pure strategy equilibria. Then, the collection $\{(\hat{w}^H,\hat{A}^H), (\hat{w}^L,\hat{A}^L), \hat{p}, \hat{\rho}(w,A)\}$ forms a sequential equilibrium (Kreps and Wilson, 1982) if the following conditions are satisfied

i) Optimality for the retailer

$$\hat{p} = p(w,A,\hat{\rho}(w,A))$$

ii) Optimality for the manufacturer

$$(\hat{w}^i,\hat{A}^i) \in \mathrm{argmax}\ w[\alpha^i+x(p(w,A,\hat{\rho}(w,A)),A)] - A$$

iii) Beliefs are Bayes-consistent;

a) if $(\hat{w}^H,\hat{A}^H) \neq (\hat{w}^L,\hat{A}^L)$

then $\hat{\rho}(\hat{w}^H,\hat{A}^H) = 1$ and $\hat{\rho}(\hat{w}^L,\hat{A}^L) = 0$

b) if $(\hat{w}^H,\hat{A}^H) = (\hat{w}^L,\hat{A}^L)$

then $\hat{\rho}(\hat{w}^H,\hat{A}^H) = \hat{\rho}(\hat{w}^L,\hat{A}^L) = \rho^0$

c) if $(w,A) \notin \{(\hat{w}^H,\hat{A}^H), (\hat{w}^L,\hat{A}^L)\}$

then any $\hat{\rho}(w,A) \in [0,1]$ is consistent

The relatively weak requirements on belief systems give rise to the familiar multiplicity of equilibria in this model. In the following sections we progressively refine these beliefs (i.e. those in iii.c) in order to narrow down the set of sustainable equilibria.

We introduce the notation $\pi^i(w,A,\rho) = w[\alpha^i + x(p(w,A,\rho),A)] - A$. Let (w^H,A^H) be the unique maximizer of $\pi^H(w,A,1)$ and (w^L,A^L) the unique maximizer of $\pi^L(w,A,0)$ where $w^i > 0$, $A^i \geq 0$. Hence, (w^i,A^i) is the full information solution when $\alpha = \alpha^i$ and the retailer knows this. $\pi^H(w^H,A^H,1)$ and $\pi^L(w^L,A^L,0)$ are then the full information profits of, respectively, the high and the low type manufacturer.

3. Separating Equilibria

In this section we first characterize the set of sequential separating equilibria, and then move on to define and explore the notion of an undominated equilibrium. We show that there is an unique undominated sequential separating equilibrium.

Before moving on to the analysis, let us recapitulate the incentives for the high type manufacturer to mimic the low type. As seen in the previous section, the retail price is strictly increasing in ρ, the posterior probability that demand is high. Since demand is strictly decreasing in p and the manufacturer wants to sell as much as possible given w and A, both types of the manufacturer would like the retailer to believe that demand is low. Hence, for a wide range of wholesale prices and advertising levels the type H manufacturer will find it profitable to mimic the low type. To avoid this a separating equilibrium pair $(\hat{w}^L,\hat{A}^L)$ for type L will be distorted from the full information pair, (w^L,A^L), as we shall see shortly.

By definition, in any separating equilibrium $(\hat{w}^H,\hat{A}^H) \neq (\hat{w}^L,\hat{A}^L)$. It follows from Bayes-consistency that $\hat{\rho}(\hat{w}^H,\hat{A}^H) = 1$ and $\hat{\rho}(\hat{w}^L,\hat{A}^L) = 0$. Clearly, in any sequential separating equilibrium $(\hat{w}^H,\hat{A}^H) = (w^H,A^H)$, that is, in contrast to the low type, the type H manufacturer adopts his full information solution. To see this, note that if it was not the case, deviating to the full information solution would always give greater profits to type H, since $\pi^H(w^H,A^H,\rho(w^H,A^H)) \geq \pi^H(w^H,A^H,1) > \pi^H(w,A,1)$ for all $(w,A) \neq (\hat{w}^H,\hat{A}^H)$. To characterize the set of separating equilibrium pairs of type L we follow usual practice by setting $\rho(w,A) = 1$ for all $(w,A) \neq (\hat{w}^L,\hat{A}^L)$, i.e. any (w,A) different from the equilibrium choice of the type L manufacturer triggers the retailer belief that demand is high with certainty. Since this is the least favourable out-of-equilibrium belief from the point of view of the manufacturer it will support the largest conceivable set of separating equilibrium pairs of wholesale prices and advertising levels for type L. Note that this system of beliefs is Bayes-consistent.

For a pair $(\hat{w}^L,\hat{A}^L)$ to be part of an equilibrium it must be true that the high type does not prefer to mimic the low type and choose $(\hat{w}^L,\hat{A}^L)$ over choosing his full information solution. Define the set H as $\{(w,A) \mid \pi^H(w,A,0) \leq \pi^H(w^H,A^H,1)\}$. Hence, H is the set of (w,A) to which type H would not deviate from (w^H,A^H) even if the retailer would infer that $\alpha = \alpha^L$. We see that $(\hat{w}^L,\hat{A}^L) \in H$ is a necessary condition for equilibrium. We also need to ensure that the type L manufacturer will adhere to his equilibrium strategy. Now, the profit from the best possible deviation[5] by type L will be $\max_{w,A} \pi^L(w,A,1)$ since $\rho(w,A) = 1$ for all $(w,A) \neq (\hat{w}^L,\hat{A}^L)$. We then define the set L as $\{(w,A) \mid \pi^L(w,A,0) \geq \max_{\tilde{w},\tilde{A}} \pi^L(\tilde{w},\tilde{A},1)\}$. Hence, with $(\hat{w}^L,\hat{A}^L)$ in L, type L will have no incentive to deviate.

The arguments above have established that necessary conditions for a separating equilibrium are $(\hat{w}^H,\hat{A}^H) = (w^H,A^H)$ and $(\hat{w}^L,\hat{A}^L) \in H \cap L$. To see that these conditions are also sufficient, note that any such configuration can be sustained as an equilibrium by setting $\rho(w,A) = 1$ for all $(w,A) \neq (\hat{w}^L,\hat{A}^L)$.

Later we shall show that sequential separating equilibria always exist. In fact, the set $H \cap L$ will typically be very large so that we get the multiplicity of sequential equilibrium outcomes usually encountered in signalling games of the kind considered in this paper. As noted earlier the main reason for this problem is the weakness of the consistency requirement embodied in the definition of sequential equilibria. In particular, only two points in the admissible space of pairs of wholesale prices and advertising levels are associated with any particular equilibrium. Hence, Bayes-consistency provides little help in specifying reasonable beliefs at out-of-equilibrium points. Most notably, consistency does not rule out that, following an out-of-equilibrium move, the retailer attaches a high probability to a type for which that move is dominated by some other move irrespective of the posterior beliefs.

Formally, we say that (w^*,A^*) is weakly dominated for type i if

$$\pi^i(w^*,A^*,0) \le \max_{w,A} \pi^i(w,A,1)$$

The notion of weak domination thus states that a pair (w^*,A^*) is dominated for type i if the profits associated with (w^*,A^*) under the most favorable beliefs, $\rho(w^*,A^*) = 0$, are no greater than the profits which can be obtained for sure under the least favorable beliefs, $\rho(w,A) = 1$.

We introduce the following natural restriction on retailer beliefs. After observing a pair (w,A) the uninformed retailer should assign zero probability to a type of the manufacturer for whom (w,A) is weakly dominated, as long as (w,A) is not weakly dominated for the other type. If a pair (w,A) is weakly dominated for both types of the manufacturer, arbitrary beliefs, $\rho(w,A) \in [0,1]$ can be assigned. This leads us to introduce the following equilibrium selection criterion:

An equilibrium is called undominated when $\hat{\rho}(w,A) = 1$ (0) if (w,A) is weakly dominated for type L (H) but not for type H (L).

From the definition of the set H we know that for all $(w,A) \in H$, $\pi^H(w,A,0) \le \pi^H(w^H,A^H,1)$. Hence, any $(w,A) \in H$ is weakly dominated for type H. Then, for all points (w,A) in $L \cap H$ that are *not* weakly dominated for type L beliefs must be $\rho(w,A) = 0$ according to the restriction above. It follows that in any undominated separating equilibrium, $(\hat{w}^L,\hat{A}^L)$ must maximize $\pi^L(w,A,0)$ over the set H. To make our problem interesting we therefore assume that $(w^L,A^L) \notin H$, that is, that the low type's full information choice is not in H. If it were, it would of course trivially be chosen in any undominated separating equilibrium.

In order to proceed to find $(\hat{w}^L,\hat{A}^L)$ when $(w^L,A^L) \notin H$ it is useful to introduce two auxiliary profit expressions. First, define for any real number α

$$\pi(w,A|\alpha) = w[\alpha+x(p(w,A,0),A)] - A$$

Hence, $\pi(w,A|\alpha)$ gives the profit to a manufacturer with demand parameter α from choosing (w,A) when the retailer with probability 1 believes that the true value of α is α^L. Let $\psi(\alpha) \equiv (w(\alpha),A(\alpha))$ be the pair which uniquely maximizes $\pi(w,A|\alpha)$, and assume that $\psi(\alpha)$ is continuous. In the appendix we show that $w(\alpha)$ is strictly increasing in α. However, in general it is not possible to say that $A(\alpha)$ is monotonic, even when A is strictly demand enhancing. Denote by $\pi(\psi(\alpha)|\alpha^H)$ the profit to the high demand manufacturer from choosing the maximizing pair $\psi(\alpha)$ of the type α, that is, the pair $(w(\alpha),A(\alpha))$ which type α would choose if the retailer for sure thinks α =

α^L. Hence

$$\pi(\psi(\alpha)\,|\,\alpha^H) = w(\alpha)[\alpha^H + x(p(w(\alpha),A(\alpha),0),A(\alpha))] - A(\alpha)$$

Note that $\rho = 0$, that is the retailer believes with certainty that $\alpha = \alpha^L$. We make the technical assumption that there exists an $\alpha < \alpha^H$ such that $\psi(\alpha) \geq 0$ and $\pi(\psi(\alpha)\,|\,\alpha^H) < \pi^H(w^H,A^H,1)$. Thus, as α gets sufficiently small the high type manufacturer will prefer his full information solution to choosing $\psi(\alpha)$ even if the retailer thinks $\alpha = \alpha^L$.

We are now ready to state the main result of this section.

Theorem 1: There exists a unique undominated separating equilibrium outcome in which $(\hat{w}^H,\hat{A}^H) = (w^H,A^H)$ and $(\hat{w}^L,\hat{A}^L) = (w(\underline{\alpha}),A(\underline{\alpha}))$ for some $\underline{\alpha} < \alpha^L$.

Proof: See Appendix.

The theorem establishes that the separating equilibrium wholesale price of the low demand type manufacturer is biased downwards relative to the full information case, whereas the wholesale price and advertising level of the high demand type are unbiased. In general, it is not possible to determine the direction of the distortion, if any, on the advertising level of type L. However, it is clear that if advertising is dissipative, that is, has no direct demand-enhancing effects, then $A(\alpha) = 0$ for all α, and we have that $\hat{A}^L = A^L = 0$. Furthermore, if $A(\alpha)$ is strictly increasing in α, which is probably the most natural conjecture, then $\hat{A}^L = A(\underline{\alpha}) < A^L = A(\alpha^L)$. Hence, advertising is biased downwards.

4. Pooling Equilibria

We have seen that the vertical market game of this paper has a unique, undominated separating equilibrium outcome. However, in general there remains a multiplicity of undominated pooling equilibria. In this section we show that invoking a more refined equilibrium notion than domination eliminates these equilibria.

The set of pooling equilibrium strategies consists of strategies $(\hat{w},\hat{A})$ where

$$\pi^H(\hat{w},\hat{A},\rho^0) \geq \pi^H(w^H,A^H,1)$$

and $$\pi^L(\hat{w},\hat{A},\rho^0) \geq \max_{w,A} \pi^L(w,A,1)$$

To support the largest set of equilibria we have again assumed $\rho(w,A) = 1$ for all $(w,A) \neq (\hat{w},\hat{A})$. This set may be very large, indeed, although it may also be empty if the prior ρ^* is sufficiently high.

We now proceed to characterize the set of undominated pooling equilibria. Denote by $H^P(\rho^*)$ the set $\{(w,A) | \pi^H(w,A,\rho^*) \geq \pi^H(w^H,A^H,1)\}$. Clearly $(\hat{w},\hat{A}) \in H^P(\rho^*)$ is a necessary condition for type H to stay in a proposed pool. Denote by $L^P(\rho^*)$ the set $\{(w,A) | \pi^L(w,A,\rho^*) \geq \pi^L(\underline{w},\underline{A},0\}$ where $(\underline{w},\underline{A}) = (w(\underline{\alpha}), A(\underline{\alpha}))$ as defined in Section 3. Since $(\underline{w},\underline{A})$ is weakly dominated for H and not for L we must have $\rho(\underline{w},\underline{A}) = 0$ in any undominated equilibrium.

Hence, type L can always secure himself $\pi^L(\underline{w},\underline{A},0)$ and any undominated equilibrium must give him at least this profit. We conclude that in any undominated equilibrium $(\hat{w},\hat{A}) \in L^P(\rho^*) \cap H^P(\rho^*)$. In fact we can prove the following theorem, which uses that $L^P(\rho^*)$ is a subset of $H^P(\rho^*)$.

Theorem 2: Any $(w,A) \in L^P(\rho^*)$ can be supported as an undominated pooling equilibrium strategy.

Proof: See Appendix.

We see that elimination of dominated strategies does not in general eliminate the multiplicity of equilibria. For low values of ρ^* a large set of undominated equilibrium outcomes will exist. In fact, we typically end up with an infinity of equilibrium outcomes. In these cases the predictive power of the model is still limited. We therefore turn to consider a more elaborate information processing system on the part of the retailer.

In the following we argue that the remaining pooling equilibria in $L^P(\rho^*)$ are destabilized if the retailer forms beliefs in a slightly more "sophisticated" manner. To formalize this argument we adapt some of the notions and ideas of Cho and Kreps (1987) to fit our context.

A system of beliefs, $\rho(w,A)$, that supports an undominated pooling equilibrium $(\hat{w},\hat{A})$, is said to be non-sensible, if there exists a pair $(w^*,A^*) \neq (\hat{w},\hat{A})$ such that

1) $\pi^H(w^*,A^*,0) < \pi^H(\hat{w},\hat{A},\rho^o)$
2) $\pi^L(w^*,A^*,0) > \pi^L(\hat{w},\hat{A},\rho^o)$

Hence, inequality 1) expresses that type H prefers his equilibrium choice $(\hat{w},\hat{A})$ to (w^*,A^*) even if (w^*,A^*) is followed by the most favourable beliefs $\rho(w^*,A^*) = 0$, whereas inequality 2) states that type L prefers the out-of-equilibrium "message" (w^*,A^*), if that message convinces the retailer that demand is actually low.

If the inequalities 1) and 2) are satisfied simultaneously, the equilibrium associated with $(\hat{w},\hat{A})$ can only be supported by a system of beliefs that assigns $\rho(w^{\prime},A^{\prime}) > 0$, which we think non-sensible. We rule out such beliefs, and an equilibrium is only said to be *refined* if it can be supported by beliefs that are no-where non-sensible. We can then prove the following:

Theorem 3: No refined pooling equilibrium exists.

Proof: See Appendix.

Thus, the refinement of out-of-equilibrium beliefs along the lines suggested by Cho and Kreps (1987), rules out pooling as a self-enforcing outcome in the signalling game considered here. Intuitively, this result follows from the observation that, relative to any proposed pooling equilibrium, the type L manufacturer can find a potentially profitable deviation that it would never pay the type H manufacturer to mimic. Faced with a deviation from an expected equilibrium, a sophisticated retailer should realize these different incentives and update beliefs accordingly. Hence, type L will in fact deviate, and the pooling equilibrium is destabilized.

5. Conclusion

By inspecting the properties of the unique separating outcome of section 3, it is easily verified that *no* potentially profitable deviations are available to type L which would not be copied by type H. It follows that the separating equilibrium component is refined, and we conclude that the vertical market game has a unique refined equilibrium outcome. With the outcome is associated the pairs $(\hat{w}^H,\hat{A}^H) = (w^H,A^H)$ and $(\hat{w}^L,\hat{A}^L) = (w(\underline{\alpha}),A(\underline{\alpha}))$.

We can further conclude that the wholesale price of the type L manufacturer is biased downwards relative to the full information price, w^L, whereas the wholesale price of type H is unbiased. Thus, averaging over the states of demand, the effect of incomplete retailer information is to lower the observed wholesale *and* retail prices. With respect to advertising, the picture is less clear, even though we conclude that type H chooses its full information level, A^H. Without adding further structure to the demand side, we cannot in general determine the direction of the advertising distortion by type L.

If, however, advertising is purely dissipative, the picture is clear since $A^L = A^H = 0$, i.e., no distortions of advertising occur. Hence, the welfare effects of asymmetric information are unambiguous if we measure total 'welfare' as the sum of manufacturer profits, retailer profits, and consumer surplus. Wholesale and retail prices are lowered on average and total welfare is increased. This net increase in welfare is composed of a loss of profits to the type L manufacturer, whereas retailer profits and consumer surplus increase. Thus, with dissipative advertising, the unambiguous improvement in retailer profits resulting from asymmetric information provides a tentative explanation of why it is left to the manufacturer alone to gather information in vertical relations of the type considered here. In addition, since consumers with a low demand also gain by keeping the retailer incompletely informed there is little a priori reason to expect consumers to solve the manufacturer's problem by providing truthful information on the state of their demand to the retailer.

* An earlier version of this paper has been presented at seminars in Hamburg and Tilburg, and we thank the participants for useful comments.

Notes

1. The extent to which the qualitative results of this paper carry over to a setting with competition at the retail stage is left to future research. However, we hazard the conjecture that, with Bertrand competition between geographically dispersed and incompletely informed retailers, the main qualitative results would continue to hold. The validity of this conjecture clearly depends on the details of the model of retail competition, but, with geographical dispersion the goods offered for sale by retailers are imperfect substitutes, and mark-ups and retailer profits can be positive in equilibrium, which is an important feature of the signalling game analyzed.

2. Bagwell and Ramey (1990) also consider a model where the incentives of the incumbent are "turned upside down" so that a high demand is signalled. The quantitative result are changed, but the qualitative features of equilibria are preserved.

3. Two remarks should be made at this point. First of all, separating equilibria may fail to exist in the model of Bagwell and Ramey (1990), whereas existence is proved for the present model (see the proof of Theorem 1). Secondly, Bagwell and Ramey claim that both separating and pooling equilibria survive the equilibrium refinements, and they state necessary conditions. However, these conditions are not sufficient, and it turns out that the analysis can be strengthened considerably to prove that, under the assumptions they make, *no* pooling equilibrium remains (this is shown in Albæk and Overgaard (1991)).

4. The introduction of constant unit costs of production and retailing would have no effect on the qualitative results of the paper. The same holds for a general advertising cost function.

5. We assume that such a best deviation exists.

Appendix

Proof of Theorem 1

We first show that $w(\alpha)$ is strictly increasing in α. Pick $\alpha_1 < \alpha_2$, and let $(w_1,A_1) = (w(\alpha_1), A(\alpha_1))$, $(w_2,A_2) = (w(\alpha_2), A(\alpha_2))$. Then

$$w_1[\alpha_1+x(p(w_1,A_1,0),A_1) - A_1 - w_2[\alpha_1+x(p(w_2,A_2,0),A_2)] + A_2 > 0$$

$$\text{(A1)}\quad w_2[\alpha_2+x(p(w_2,A_2,0),A_2)] - A_2 - w_1[\alpha_2+x(p(w_1,A_1,0),A_1)] + A_1 > 0$$

Add the inequalities to get

$$(w_1-w_2)(\alpha_1-\alpha_2) > 0$$

Hence, $w_1 < w_2$.

Now, assume $\alpha_1 < \alpha_2 < \alpha^H$, and substitute α^H into (A1)

$$w_2[\alpha^H+x(p(w_2,A_2,0),A_2)] - A_2 - w_1[\alpha^H+x(p(w_1,A_1,0),A_1)] + A_1 > 0$$

Hence, $\pi(\psi(\alpha)|\alpha^H)$ is strictly increasing in α for $\alpha < \alpha^H$. Since, by assumption, there exists $\alpha < \alpha^H$ such that $\psi(\alpha) \geq 0$ and $\pi(\psi(\alpha)|\alpha^H) < \pi^H(w^H,A^H,1)$, the above result and the continuity of $\psi(\alpha)$ tells us there exists a unique $\underline{\alpha} < \alpha^H$ such that $\psi(\underline{\alpha}) \geq 0$ and $\pi(\psi(\underline{\alpha})|\alpha^H) = \pi^H(w^H,A^H,1)$. Since we have assumed that $(w^L,A^L) = (w(\alpha^L), A(\alpha^L)) \notin H$ we must have $\pi(\psi(\alpha^L)|\alpha^H) > \pi^H(w^H,A^H,1)$. Therefore we know that $\underline{\alpha} < \alpha^L$.

We now show that in any separating equilibrium $\pi^H(\hat{w}^L,\hat{A}^L,0) = \pi^H(w^H,A^H,1)$. Suppose not, and let $(\underline{w},\underline{A}) = (w(\underline{\alpha}),A(\underline{\alpha}))$. Then

$$\underline{w}[\alpha^H+x(p(\underline{w},\underline{A},0),\underline{A})] - \underline{A} - \hat{w}^L[\alpha^H+x(p(\hat{w}^L,\hat{A}^L,0),\hat{A}^L)] + \hat{A}^L > 0$$

$$\text{(A2)}\quad \hat{w}^L[\alpha^L+x(p(\hat{w}^L,\hat{A}^L,0),\hat{A}^L)] - \hat{A}^L - \underline{w}[\alpha^L+x(p(\underline{w},\underline{A},0),\underline{A})] + \underline{A} \geq 0$$

since $(\hat{w}^L,\hat{A}^L)$ maximizes $\pi^L(w,A,0)$ on H.

Then

$$(\underline{w}-\hat{w}^L)(\alpha^H-\alpha^L) > 0$$

and

$$\underline{w} > \hat{w}^L$$

Substituting $\underline{\alpha} < \alpha^L$ into (A2) gives

$$\hat{w}^L[\underline{\alpha}+x(p(\hat{w}^L,\hat{A}^L,0),\hat{A}^L)] - \hat{A}^L - \underline{w}[\underline{\alpha}+x(p(\underline{w},\underline{A},0),\underline{A})] + \underline{A} > 0$$

which is a contradiction since $\psi(\underline{\alpha})$ maximizes $\pi(w,A|\underline{\alpha})$. Thus, we must have

$\pi^H(\hat{w}^L,\hat{A}^L,0) = \pi^H(w^H,A^H,1)$.

Now, we still need to show that $(\underline{w},\underline{A})$ is the unique pair which maximizes $\pi^L(w,A,0)$ under the condition that $\pi^H(w,A,0) = \pi^H(w^H,A^H,1)$. Therefore, pick any $(w,A) \neq (\underline{w},\underline{A})$ such that $\pi^H(w,A,0) = \pi^H(w^H,A^H,1)$. Then

$$\underline{w}[\underline{\alpha}+x(p(\underline{w},\underline{A},0),\underline{A})] - \underline{A} - w[\underline{\alpha}+x(p(w,A,0),A)] + A > 0$$

$$\text{(A3)} \qquad w[\alpha^H+x(p(w,A,0),A)] - A - \underline{w}[\alpha^H+x(p(\underline{w},\underline{A},0),\underline{A})] + \underline{A} = 0$$

Adding gives

$$(\underline{w}-w)(\underline{\alpha}-\alpha^H) > 0$$

whence

$$\underline{w} < w$$

Evaluate

$$\begin{aligned}&\pi^L(\underline{w},\underline{A},0) - \pi^L(w,A,0)\\ &= \underline{w}[\alpha^L+x(p(\underline{w},\underline{A},0),\underline{A})] - \underline{A} - w[\alpha^L+x(p(w,A,0),A)] + A\end{aligned}$$

Add (A3) to get

$$\begin{aligned}&\underline{w}[\alpha^L+x(p(\underline{w},\underline{A},0),\underline{A})] - \underline{A} - w(\alpha^L+x(p(w,A,0),A)] + A\\ &+ w[\alpha^H+x(p(w,A,0),A)] - A - \underline{w}(\alpha^H+x(p(\underline{w},\underline{A},0),\underline{A})] + \underline{A}\\ &= (\underline{w}-w)(\alpha^L-\alpha^H) > 0\end{aligned}$$

Hence, $(\underline{w},\underline{A}) = (w(\underline{\alpha}),A(\underline{\alpha}))$ is the unique maximizer of $\pi^L(w,A,0)$ given $\pi^H(w,A,0) = \pi^H(w^H,A^H,1)$.

To show the existence of the equilibrium we need to show that $\psi(\underline{\alpha})$ is in L (by definition; $\psi(\underline{\alpha}) \in$ H). Suppose not. Define $(\hat{w},\hat{A})$ as the unique maximizer of $\pi^L(w,A,1) = w[\alpha^L+x(p(w,A,1),A)] - A$. Then

$$\begin{aligned}&\hat{w}[\alpha^L+x(p(\hat{w},\hat{A},1),\hat{A})] - \hat{A} - \underline{w}[\alpha^L+x(p(\underline{w},\underline{A},0),\underline{A})] + \underline{A} > 0\\ &\underline{w}[\alpha^H+x(p(\underline{w},\underline{A},0),\underline{A})] - \underline{A} - \hat{w}[\alpha^H+x(p(\hat{w},\hat{A},1),\hat{A})] + \hat{A} > 0\end{aligned}$$

By adding we infer

$$(\underline{w}-\hat{w})(\alpha^H-\alpha^L) > 0$$

and

$$\underline{w} > \hat{w}$$

But then

$$\hat{w}[\underline{\alpha}+x(p(\hat{w},\hat{A},1),\hat{A})] - \hat{A} - \underline{w}[\underline{\alpha}+x(p(\underline{w},\underline{A},0),\underline{A})] + \underline{A} > 0$$

which is a contradiction. Hence, $(\underline{w},\underline{A}) \in$ L and a separating equilibrium exists. This

Since $x(p(\hat{w},\hat{A},0),\hat{A}) > x(p(\hat{w},\hat{A},1),\hat{A})$ we get

$$\hat{w}[\underline{\alpha}+x(p(\hat{w},\hat{A},0),\hat{A})] - \hat{A} - \underline{w}[\underline{\alpha}+x(p(\underline{w},\underline{A},0),\underline{A})] + \underline{A} > 0$$

concludes the proof of Theorem 1.

Proof of Theorem 2

First we show that any (w,A) in $L^P(\rho^*)$ must also be in $H^P(\rho^*)$. Suppose not, and remember that $\pi^H(\underline{w},\underline{A},0) = \pi^H(w^H,A^H,1)$. Then

$$\underline{w}[\alpha^H+x(p(\underline{w},\underline{A},0),\underline{A})] - \underline{A} - w[\alpha^H+x(p(w,A,\rho^*),A)] + A > 0$$
$$w[\alpha^L+x(p(w,A,\rho^*),A)] - A - \underline{w}[\alpha^L+x(p(\underline{w},\underline{A},0),\underline{A})] + \underline{A} \geq 0$$

Adding gives

$$(\underline{w}-w)(\alpha^H-\alpha^L) > 0$$

whence

$$\underline{w} > w$$

But then

$$w[\underline{\alpha}+x(p(w,A,\rho^*),A)] - A - \underline{w}[\underline{\alpha}+x(p(\underline{w},\underline{A},0),\underline{A})] + \underline{A} > 0$$

Since $x(p(w,A,0),A) > x(p(w,A,\rho^*),A)$ we get

$$w[\underline{\alpha}+x(p(w,A,0),A)] - A - \underline{w}[\underline{\alpha}+x(p(\underline{w},\underline{A},0),\underline{A})] + \underline{A} > 0$$

which is a contradiction. The theorem is then proved by noting that the following beliefs sustains the undominated pooling equilibrium:

$$\forall(w,A) \notin H(\rho^*);\ \rho(w,A) = 0$$
$$\forall(w,A) \in H(\rho^*)\backslash L(\rho^*);\ \rho(w,A) = 1$$
$$(w,A) = (\hat{w},\hat{A});\ \rho(w,A) = \rho^*$$
$$\forall(w,A)\in L(\rho^*)\backslash\{\hat{w},\hat{A}\};\ \rho(w,A) = 1.$$

Proof of Theorem 3

Fix *any* undominated pooling equilibrium pair $(\hat{w},\hat{A}) \in L^P(\rho^*)$ such that $\rho(\hat{w},\hat{A}) = \rho^*$. Now, the earlier assumptions guarantee the existence of an $\tilde{\alpha} < \alpha^H$ such that

$$\text{(A4)}\quad \hat{w}[\alpha^H+x(p(\hat{w},\hat{A},\rho^*),\hat{A})] - \hat{A} - w(\tilde{\alpha})[\alpha^H+x(p(w(\tilde{\alpha}),A(\tilde{\alpha}),0),A(\tilde{\alpha})] + A(\tilde{\alpha}) = 0$$

where $(w(\tilde{\alpha}),A(\tilde{\alpha})) = \psi(\tilde{\alpha}) \in \mathbf{R}^2_+$. By construction we also have

(A5) $w(\tilde{\alpha})[\tilde{\alpha}+x(p(w(\tilde{\alpha}),A(\tilde{\alpha}),0),A(\tilde{\alpha}))] - A(\tilde{\alpha}) - \hat{w}[\tilde{\alpha}+x(p(\hat{w},\hat{A},\rho^*),\hat{A})] + \hat{A} > 0$

Add (A4) and (A5) to get

$$(\hat{w}-w(\tilde{\alpha}))(\alpha^H-\tilde{\alpha}) > 0$$

or

$$\hat{w} > w(\tilde{\alpha})$$

Now, evaluate

$$\hat{w}[\alpha^L+x(p(\hat{w},\hat{A},\rho^*),\hat{A})] - \hat{A} - w(\tilde{\alpha})[\alpha^L+x(p(w(\tilde{\alpha}),A(\tilde{\alpha}),0),A(\tilde{\alpha}))] + A(\tilde{\alpha})$$

Subtract (A4) to obtain

$$(\hat{w}-w(\tilde{\alpha}))(\alpha^L-\alpha^H) < 0$$

Hence, the low type strictly prefers $\psi(\tilde{\alpha})$ to the pooling pair if beliefs are updated to $\rho(\psi(\tilde{\alpha})) = 0$. By continuity, we can find points (w,A) in a close neighbourhood of $\psi(\tilde{\alpha})$ that are strictly non-preferred by the high type and strictly preferred by the low type if beliefs are updated to $\rho(w,A) = 0$. Hence, $(\hat{w},\hat{A})$ collapses. ■

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