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COORDINATION ECONOMIES, ADVERTISING AND SEARCH BEHAVIOR IN RETAIL MARKETS

by

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Many observed advertisements seem at odds with rational behavior. In a variety of ads, mostly on T.V. and radio, multiproduct sellers provide little hard information, choosing instead to impart only vague slogans that are suggestive of good deals. Examples are plentiful: a hardware store chain exclaims, "The more we sell, the lower the price; the lower the price, the more we sell!"; a pharmacy chain alludes to manufacturer quantity discounts and promises that its "power buying" translates into greater "buying power" for customers; and a furniture outlet concludes, "We're better because we're bigger, and we're bigger because we're better!"[1] In these ads and many others, the essential message seems to be that large firms offer better deals. Yet, inasmuch as the ads provide little hard evidence that the firms truly do offer better deals, it is not at all clear why consumers respond to such expensive, ostensibly uninformative retail advertisements.

We offer a new model of the retail firm that provides an explanation for this phenomenon. The firm is assumed to choose a selling technology, a product line, and prices. Improvements in selling technology act to lower the firm's marginal and total selling costs, and an expansion in the product line increases the firm's sales for any given number of customers. We further allow for the possibility of declining marginal costs, which can be motivated by the prevalence of manufacturer quantity discounts in retail markets. Using this framework, we show that the firm's various actions are tied together by a web of complementarities: greater investment in selling technology, an expansion in the product line, and lower prices are mutually reinforcing responses to an increase in expected market share. Since firms offer greater variety and lower prices when their expected sales volume expands, it follows that consumers as well as active firms benefit when sales are concentrated among fewer firms. This gives rise to the possibility for mutually beneficial *coordination economies* in retail markets.

Coordination economies may be difficult to achieve, however, when firms cannot directly communicate product variety and price information. We explore the possibility that ostensibly uninformative advertising may play a role in this instance, by directing consumers to firms that expect to capture the largest market share and thus offer the best deals. We first present this idea in a very general context: if firms that advertise have higher expected market share, then advertising firms will be led to offer better deals, and so the original hypothesis - advertising increases expected market share - becomes entirely consistent with rational consumer behavior.

This general approach illustrates the rationality of consumers' responsiveness to retail advertising, but it does not offer an equilibrium determination of the level of advertising, the extent of entry, or the welfare consequences of advertising restrictions. To examine these and other issues, we develop a simple and fully-specified equilibrium model of retail advertising. Consumers are subdivided into an informed group that observes the rank order of firms' advertising expenditures, and an uninformed group that observes no advertising information. Consumers can observe variety and price information only through search. We posit that consumers use simple rules of thumb to direct their search; in particular, informed consumers may use an *advertising search rule*, which guides search to the firm(s) with the highest advertising level.

We construct an advertising equilibrium, in which endogenous entry determines the number of firms, and firms choose positive advertising levels in hopes of capturing the informed consumers. Zero profits are earned in this equilibrium, as the returns from large expected market share are dissipated via high advertising expenditures. Moreover, since firms with higher advertising anticipate greater expected market share, they also offer better deals. This means that the advertising search rule is optimal among all possible search rules for the informed consumers, as it directs them to the best deals in the market. Once again, it follows that consumers' sensitivity to seemingly uninformative advertisements emerges as an entirely rational inference that coordination economies are present.

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We compare the advertising equilibrium to a no-advertising benchmark, in which all consumers use a random search rule that ignores advertising information. Since advertising expenditures reduce firms' profits in the advertising equilibrium, fewer firms enter the market relative to the no-advertising benchmark, and thus concentration is higher. Social surplus is also strictly higher in the advertising equilibrium, as advertising concentrates the purchases of informed consumers and allows coordination economies to be more fully realized. Further, the informed consumers convey a positive externality on the uninformed, to the extent that the latter benefit from the better deals that the firms offer in the advertising equilibrium.

Our work relates to several strands of literature. First, our equilibrium model of advertising bears a similarity to theories of sales in which firms move randomly between high-price and low-price episodes. Random sales have been previously analyzed in a number of models, including those by Kenneth Burdett and Kenneth L. Judd (1983), Robert W. Rosenthal (1980), Dale O. Stahl (1989) and Hal R. Varian (1980). The distinctive feature of our model is that sales also are associated with an increase in product variety and an intensification of advertising. Sales of this kind, where sellers temporarily increase their stock, reduce their prices and advertise heavily, are quite commonly observed in retail markets.

Interpreted more broadly, our results provide an explanation for empirical puzzles uncovered by Lee Benham (1971). In his investigation of the retail eyeglass industry, Benham found that eyeglass prices were lower, market structure was more concentrated, and large-scale, low-price outlets were more common in markets that permitted advertising, even when state law prohibited advertisements from mentioning price information. John Cady (1976) and William Luksetich and Harold Lofgreen (1976) reported similar findings for the retail prescription drug and liquor markets, respectively. These surprising effects of non-price advertising may be readily understood in terms of our model: coordination economies may be difficult to achieve when all advertising is banned, but once advertising is allowed it need not convey hard information to play its coordination role. Further, we give an explanation for the

commonly-observed coexistence of large-scale, high-variety, low-price, high-advertising retailers with their small-scale, low-variety, high-price, low-advertising counterparts.

Finally, this paper builds on a body of research that links dissipative advertising expenditures to communication of experience or search attributes to consumers. For example, Richard E. Kihlstrom and Michael H. Riordan (1984), Paul Milgrom and John Roberts (1986) and Phillip Nelson (1974) develop models in which advertising signals product quality information that consumers otherwise can acquire only by experiencing the good. While this research has emphasized the advertising activity of a manufacturer, we differ in focusing on the *retailer's* use of advertising to communicate store-specific price and variety selections.

In our 1990 paper, we present an analysis of advertising for search goods that develops themes similar to those reported here. There are four key differences between the two papers. First, in contrast to the earlier paper, the present paper employs theorems for supermodular functions, as developed by Milgrom and Roberts (1990), Milgrom and Christina Shannon (1991) and Donald Topkis (1978), and thereby provides a comprehensive model of retail coordination economies. This model, which allows for random market shares, leads natuarally to a general perspective on the role of retail advertising. A second difference concerns the behavior of consumers in the equilibrium models. In the earlier paper, consumers directly observe the actual level of advertising expenditures by all firms, and they use sophisticated forward-induction reasoning in drawing inferences from these observations. This approach differs from that of the present paper, where consumers observe only the rank-order of advertising expenses and search according to a plausible (but still fully-rational) rule-of-thumb. Third, a consequence of forward-induction reasoning for complete-information games is that advertising arises only off the equilibrium path, to upset inefficient configurations. In the equilibrium model of the present paper, however, positive advertising occurs on the equilibrium path. Finally, entry is endogenous in the equilibrium model developed below, and this makes possible a more complete analysis of the welfare consequences of advertising restrictions.

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The remainder of the paper is organized as follows. Section I develops our model of coordination economies for the retail firm in a simple constant-marginal-cost setting. The general role for advertising also is developed in this section. Section II presents an equilibrium model of trading on retail markets and derives properties of advertising and random-search equilibria. In Section III, the more complex case of declining marginal costs is introduced and analyzed, and Section IV concludes. The Appendix collects all proofs not found in the main text.

I. COORDINATION ECONOMIES IN RETAIL MARKETS

A. FRAMEWORK

Our central hypothesis is that a firm and consumers each may benefit from coordination of purchase activities at the firm. That is, when a firm expands its market share, both the firm and its customers are made better off. This *coordination hypothesis* is especially compelling in the case of retail markets, where there are a variety of factors that give rise to coordination economies. In this section, we develop a model of a retail enterprise that illustrates some of these factors.

Specifically, we characterize the optimal pricing, selling technology, and variety choices for a single retail firm facing an uncertain market share. The firm's decision variables are thus its price level, $P \in R_+ \equiv [0,\infty)$, its technology, $K \in R_+$, and its number of products or level of variety, $V \in R_+$.[2] Assuming that consumers have identical preferences, the firm's demand side is determined by a market size parameter. Let M be the number or mass of consumers visiting the firm. We allow that the firm operates under uncertainty, with M being drawn from the interval $[M_s, M_b]$ according to the distribution function $H(M)$, where $M_b \geq M_s > 0$ and the expected value of M is $E > 0$.

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[2]Here we follow Milgrom and Roberts (1990) and posit that a single price is selected for all products offered; this is sensible if the firm's products all have symmetric demand and cost functions (as we assume below). Importantly, this framework does not rule out cross-product interactions. For example, the firm may sell a set of differentiated products, each with symmetric demand and cost functions. As we show in our 1992 paper, our results hold also when demand and cost functions are asymmetric and independent across products.

Notice that the expected number of visiting consumers, E, is not permitted to depend on the firm's price, technology and variety choices. We have in mind that consumers must actually visit the firm in order to observe these selections; our focus in this section is then on the effect that a larger expected number of consumers has on the firm's optimal choice of price, technology and variety. This exercise is of direct interest and also serves as a building block for subsequent sections, where multiple firms and consumer search are formally investigated.

Consumers are assumed to have positive demand for each of the products in the firm's product line. Their preferences are standard and are summarized as follows:

A1: For each good, there is a twice-continuously-differentiable demand function, $D(P)$: $R_+ \rightarrow R_+$, satisfying $D(P) > 0 > D'(P)$.

With Q interpreted to be quantity of output, we may now characterize the firm's selling cost function:

A2: For each good, there is a twice-continuously-differentiable selling cost function, $C(Q,K)$: $R_+ \times R_+ \rightarrow R_+$, satisfying

i). $C(Q,K) = c(K)Q + g(K)$

ii). $c(K) \geq 0 \geq c'(K)$

iii). $g(K) \geq 0 \geq g'(K)$.

A2 embodies the assumption that the marginal costs of selling are constant in output; consideration of declining marginal selling costs is deferred to Section III. A2 further specifies that a higher level of technology weakly reduces marginal and total selling costs. This is a natural assumption, if we think of K as representing such items as more advanced service machinery (barcode-reading cash registers), improved storage technology (better refrigeration,

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bigger shelves, larger inventory storage area), or superior delivery systems (privately owned warehouses and trucks). In general, we envisage a fixed investment in technology as enabling a reduction in the use of the variable inputs associated with selling.

We come now to our assumption regarding the fixed costs associated with purchasing a better technology and securing and administering a product line:

<u>A3</u>:   There is a twice continuously differentiable technology-cost and stocking-cost function, $S(K,V): R_+ \times R_+ \rightarrow R_+$, satisfying $S(K,V) > 0 \geq S_{KV}$.

The key assumptions here are that there are positive fixed costs to operation, and that better technologies do not increase the incremental fixed costs associated with product line expansion.

With this basic framework in place, we may define the net revenue per product for a fixed market share M to be

(1). $r(P,K,M) = PD(P)M - C(D(P)M,K)$

so that the per product net revenue when market share is random is

(2). $R(P,K,E) = \int_{M_S}^{M_b} r(P,K,M)dH(M) = (P-c(K))D(P)E - g(K).$

We are now prepared to define the firm's expected profits as

(3). $VR(P,K,E) - S(K,V).$

B. COMPLEMENTARITIES

We illustrate next that the assumptions made above give a framework in which lower prices, better technology, larger variety, and higher expected market share are complementary to one another. Using the mathematics of complementarities as exposited by Milgrom and Roberts (1990), we then shall be able to establish the comparative statics results that underlie our coordination hypothesis.

Complementarities may be defined in terms of supermodular functions. Assuming that a function $f: R_+^k \to R_+$ is twice continuously differentiable, f is supermodular if and only if $f_{ij} \geq 0$, for all $i \neq j$. Thus an increase in one variable raises the marginal value of increasing all other variables for a supermodular function. Unfortunately, the expected profits function as given in (3) above is not supermodular in (-P, K, V, E). The difficulty is that complementarities may fail to exist if price is set below marginal cost; for instance, greater expected market share makes *lower* variety more attractive when price is set at a very low level.[3]

To avoid the problems created by suboptimal price choices, we examine instead a reduced-form expected-profits function, in which the optimal price is embedded. First, we require an additional assumption that the (fixed-technology) optimal price is well-defined:

<u>A4</u>:   R has a unique maximizer, $\tilde{P}(K)$, at which $R > 0 = R_P > R_{PP}$.

Examination of the first order condition reveals that the optimal price must exceed the marginal costs of selling, c(K).

We now have:

<u>Lemma 1</u>:   Under A1-A4, $\tilde{P}$ is nonincreasing in K.

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[3]This problem of suboptimal prices also arises in the analysis of modern manufacturing that Milgrom and Roberts (1990) present.

Thus, under our assumptions, higher technology cannot increase prices. This result follows from A2, under which marginal costs are nonincreasing in technology. It should be noted that a strict reduction in price occurs if marginal cost strictly declines in technology.

We may now define expected profits under optimal pricing:

(4). $\quad \Pi(K,V,E) = VR(\tilde{P}(K),K,E) - S(K,V)$.

With this definition at hand, we have our second lemma:

Lemma 2: $\qquad$ Under A1-A4, $\Pi(K,V,E)$ is supermodular in (K,V,E).

Thus, when price is set optimally, an increase in any one of the variables, K,V, or E, weakly raises the benefit from increasing the others. Intuitively, as expected market share increases, the benefit from an additional variety cannot decrease, since the markup of price over marginal costs for a new product is then received on more buyers. Similarly, the benefit from lowering total costs with better technology is weakly enhanced by a greater expected sales volume, since $C_{QK} \leq 0$ under A2. Finally, with $C_K \leq 0$ and $S_{KV} \leq 0$ under A2 and A3, an improved technology does not decrease the net revenue obtainable from a new product and does not increase the fixed costs associated with adopting the new variety, and so higher technology and greater variety are mutually reinforcing consequences of expanded expected market share.

One thus sees the makings of a broad pattern, whereby higher expected market share results in greater variety and better technology, with each effect reinforcing the other. Note moreover that under Lemma 1 prices will not increase, since better technology is conducive to lower prices. Using the mathematics of complementarities, we show now that this intuition has a rigorous and general representation.

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C.   COMPARATIVE STATICS

To begin, we must be clear as to the sets from which K and V are selected. We assume only that:

A5:   K ∈ **K** and V∈ **V**, where **K** and **V** are compact subsets of R_+ and where min **V** > 0.

Thus, K and V may be drawn from finite or infinite sets. The former is especially compelling, if V corresponds to the number of products to offer and K indexes the particular model of a barcode-reading cash register to purchase, for example. Finally, it is convenient to avoid the V = 0 case; one may think of V > 0 as a precondition for meaningful entry.

The formal results given in Milgrom and Roberts (1990) may be invoked to obtain the following theorem:

Theorem 1 :   Under A1-A5, the maximizer set, S(E) = argmax {Π(K,V,E) | K∈ **K**,V∈ **V**}, is nonempty and contains its component-wise greatest and least elements, (K*(E), V*(E)) and (K*(E), V*(E)), respectively; furthermore, both of these elements are nondecreasing in E.

It should be emphasized that no concavity assumptions are made on the function Π; a consequence is that multiple maximizers may exist. The theorem above handles this case, and indicates that the bounds on the set of maximizers are nondecreasing. In this sense, the whole set of maximizers is nondecreasing in expected market share. We thus may adopt the convention of focusing on the maximal solution, (K*(E), V*(E)).

Our last step is to combine Theorem 1 and Lemma 1 in order to determine the relation between the firm's optimal price choice and its expected market share. Let us define the firm's monopoly price, P*(E), by

(5).   P*(E) = $\tilde{P}$(K*(E)).

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We now have the following corollary:

Corollary 1: Under A1-A5, $K^*(E)$ and $V^*(E)$ are nondecreasing in E, while $P^*(E)$ is nonincreasing in E.

On the basis of this corollary, we may conclude that greater expected market share generates (weakly) better technology, higher variety, and lower prices.

D. COORDINATION ECONOMIES

We say that *coordination economies* exist if a firm that expects higher market share earns greater expected profits *and* offers better deals to consumers. We refer to the first half of this definition as *the better profit property*, and we term the second portion *the better deal property*.

To investigate the better profit property, we first define maximized expected profits:

$$(6). \quad \Pi^*(E) = \Pi(K^*(E),V^*(E),E).$$

The better profit property may now be stated:

Lemma 3: Under A1-A5, $\Pi^*(E)$ is continuous and increasing in E.

Thus, $\Pi^*(E)$ is indeed increasing in expected market share, and this follows because $P^*(E)$ exceeds marginal cost; continuity is a consequence of the Maximum Theorem.

The better deal property requires a specification of consumer preferences. We assume only that:

A6:   Each consumer possesses a welfare function, $W(P,V)$: $R_+ x R_+ \rightarrow R_+$, where $W(P,0) = 0$ and

where $W(P,V)$ is increasing in V and decreasing in P.

Consumer welfare at a maximizing firm is thus defined by

(7). $W^*(E) = W(P^*(E),V^*(E))$.

An immediate consequence of A6 and Corollary 1 is our better deal property:

Corollary 2:   Under A1-A6, $W^*(E)$ is nondecreasing in E.

Thus, coordination economies exist, since a firm that expects higher market share earns greater expected profits (Lemma 3) and offers better deals (Corollary 2).

Coordination economies may be expected to be even more pronounced under a weakening of some of our assumptions. As argued below, declining marginal selling costs would act to reinforce the better deal property. Also, we ignore any interaction in costs across products, even though such effects might only strengthen our argument. As Baumol, Panzar and Willig (1982, Ch. 4) show, when a "public input" contributes to the output of all goods produced by a multiproduct firm, the cost function exhibits cost complementarities in that the marginal cost of any one good is nonincreasing in the output of other goods. Sales personnel as well as the physical selling area would appear to serve as public inputs in the retail firm context. Cross-product cost interactions thus provide an additional channel through which expanded market share might induce cost - and therefore price - reductions.[4]

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[4]Inventory considerations represent another source of coordination benefits. In particular, a firm that expects greater market share is subject to less demand variability (assuming that individual consumer demands are random but not perfectly correlated), and this in turn may enable it to reduce costs by turning inventory over more quickly and by reducing the frequency of idleness for sales clerks. Walter Oi (1992) provides an excellent overview of these and other points. We thank Tim Bresnahan for this reference.

E.   ADVERTISING AND COORDINATION: A GENERAL PERSPECTIVE

We now illustrate a general role for advertising when coordination economies exist. Let A be an advertising expenditure, with profits now given by $\Pi - A$, and allow that the expected market share depends on A. We have:

<u>Corollary 3</u>:   Under A1-A6, if in addition $E(A)$ is nondecreasing in A, then $P^*(E(A))$ is nonincreasing in A, and $K^*(E(A))$, $V^*(E(A))$ and $W^*(E(A))$ are all nondecreasing in A.

Intuitively, if high advertising increases expected market share, then the presence of coordination economies ensures that a high-advertising firm offers better deals. It follows that, when consumers respond positively to advertising, a firm that advertises heavily behaves in a manner that justifies the consumers' original responsiveness to advertising. In this general sense, consumers' responsiveness to advertising is entirely rational.

While we have focused on a model with a single firm, the insights are more general. For example, the relation of E to a firm's advertising activity may depend in part on the advertising behavior of rival firms. Still, as long as E is nondecreasing in the given firm's advertising level, the firm is led to offer better deals as it advertises more.[5] Similarly, the results in Corollary 3 are consistent with a model in which consumers each receive only noisy signals as to the advertising expenditure of a given firm.

The general model does have some limitations, however. In particular, the level of advertising is not endogenized and consequently the effect of advertising on the entry of firms and on welfare are not treated. These important extensions are handled in the next section,

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[5]Note also that this conclusion requires only that advertising increase a firm's mean market share. Thus, the conclusion is compatible with the notion that advertising redistributes a fixed market size among firms, in which case M_b and M_s would be independent of A, and it is also compatible with the idea that advertising expands the market customer base, with M_b and/or M_s increasing in A.

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where we apply the general framework presented above to a particular, fully-specified equilibrium model of advertising.

II.   AN EQUILIBRIUM MODEL OF ADVERTISING AND SEARCH

A.   THE MODEL

We now construct a specific equilibrium model of retail advertising. Assume that there exist a large number of identical firms that conform to the assumptions made above. Market interaction between consumers and firms is represented by the following extensive-form game.

Stage 1.   The firms simultaneously decide whether to enter the market or stay out. Entering firms' payoffs are Π - A. Firms that stay out can make no further choices and earn zero profits.

Stage 2.   Firms that have entered observe the total number of entrants, and then make simultaneous choices of Z and A, where Z $\equiv$ (P,K,V).

Stage 3.   Each consumer visits one of the firms that have entered, and makes any desired purchases given the Z that has been chosen by the visited firm.

Notice that we have not yet specified the information that each consumer has when picking a firm to visit; we develop these assumptions below. Observe also that a consumer is assumed to visit only one firm. This assumption greatly simplifies the analysis of equilibria, as it ensures that a firm expecting E buyers simply chooses the corresponding monopoly price, technology and variety levels.[6]

We assume that consumers cannot observe any part of Z prior to making their visitation decision; thus, price and variety information cannot be directly communicated in this market. Proportion I $\in$ (0,1) of the consumers do gain some information from advertising expenditures, however, in that they can observe the *rank-ordering* of firms in terms of advertising levels.

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[6]We show in our 1992 paper that our main insights are robust to the possibility of sequential search by buyers. See also note 12 below.

Consumers possessing this ordinal information are called *informed*. The remaining proportion U = 1 - I of consumers observe nothing about advertising and are called *uninformed*.[7]

Finally, recalling that the total consumer population has unit mass, we make the assumption that entry is potentially attractive:

<u>A7</u>: $\Pi^*(1) > 0$.

That is, if a firm expects to sell to all consumers and sets Z optimally, then it makes positive profit. Since $S(K,V) > 0$ implies that $\Pi^*(0) < 0$, we have from the better profit property (Lemma 3) that a unique $\bar{E} \in (0,1)$ exists such that

(8). $\Pi^*(\bar{E}) = 0$.

We maintain A1 through A7 in what follows.

B.   SEARCH RULES AND EQUILIBRIA

We adopt subgame perfect equilibrium as our basic solution concept, although in this setting it places very few restrictions on the set of possible outcomes. Since consumers cannot observe Z, the only subgames of the model consist of Stages 2 and 3 following each Stage 1 entry profile, and thus subgame perfection requires only that Nash equilibria arise following Stage 1. Any entry or advertising behavior that is off the equilibrium path can be punished by the threat of consumers who have observed the deviation to stay away from the deviating firm. A great variety of equilibrium entry and advertising profiles become possible based on such threats. Moreover, requiring consumer behavior to be sequentially rational changes nothing,

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[7]Our modeling approach in this section relates closely to that of Varian (1980). A key difference is that here the informed consumers observe only advertising information, rather than price information as in Varian's model.

since the threat to stay away from a deviant firm is utility-maximizing if consumers believe that the firm offers a very bad deal (e.g., $P = \infty$).

In this paper we handle the multiplicity problem by specifying that each consumer's search behavior conforms to a simple *rule of thumb* that maps observed entry and advertising information to visitation decisions. The rule of thumb will serve to restrict consumer responses to off-equilibrium-path behavior. At the same time, on the equilibrium path the rule is required to maximize the consumer's utility among the set of *all possible* visitation rules. In essence, we model consumers as following simple rules that are nevertheless rational, in the sense that a consumer never has an incentive to depart from his rule.

Two kinds of rules of thumb are considered. First, the *random search rule* specifies that a consumer randomly chooses which firm to visit, placing equal probability weight on each firm that has entered the market. The uninformed consumers will always be assumed to follow the random search rule. Second, the *advertising search rule* specifies that informed consumers visit the firm that has chosen the greatest level of advertising expenditure. If two or more firms are tied for the greatest level, then the informed consumers choose randomly from among them, placing equal probability weight on each of the advertising leaders.

Given the allowable search rules, two kinds of equilibria may emerge. In a *random equilibrium*, all consumers use the random search rule, and thus the informed consumers ignore their advertising information. In an *advertising equilibrium*, the informed use the advertising search rule. Finally, in addition to the restrictions on consumer search rules, we require that firms make only nonrandom entry decisions in Stage 1.[8]

Letting $Z^*(E) \equiv (P^*(E), K^*(E), V^*(E))$ denote the optimal price, technology, and variety choices for a firm with expected market share E, we may characterize random equilibria as follows:

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[8]The restriction to pure entry strategies is for simplicity only. It is straightforward to introduce mixed entry strategies for a population of N firms, and our basic results continue to hold for symmetric mixed random and advertising equilibria.

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<u>Proposition 1:</u> A random equilibrium arises if and only if in any subgame in which N firms have entered, each entering firm chooses

(9). $\quad Z = Z^*(1/N), \quad A = 0$

and the equilibrium number of entering firms N^R satisfies

(10). $\quad 1/N^R \geq \bar{E} > 1/(N^R+1)$.

Sufficiency follows from the fact that, given the random search rule, entering firms' best responses are symmetric, and thus the random search rule is a best response for each consumer. Further, because advertising deviations do not affect the search behavior of the informed, the entering firms necessarily choose zero advertising in each subgame.

We turn now to advertising equilibria. We will restrict attention to advertising equilibria in which entering firms' strategies are symmetric within each subgame, which are called symmetric advertising equilibria. Further, it will be necessary to allow for mixed strategies in the choices of Z and A, as non-existence of pure-strategy advertising equilibria of this model, either symmetric or asymmetric, follows from standard arguments (Varian, 1980). When firms play mixed advertising strategies, the market share of an entering firm becomes a random variable, since the firm becomes uncertain whether or not it will capture the informed consumers.[9]

To characterize the set of symmetric advertising equilibria, we begin by fixing a subgame in which N ≥ 2 firms have entered. Let F(A) give the distribution of each firm's

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[9]It is straightforward, however, to reinterpret our mixed-strategy equilibria as pure-strategy equilibria of a plausible incomplete-information game, i.e., our mixed-strategy equilibria can be readily purified. This is demonstrated in our 1992 paper.

advertising expenditures in the subgame. Given the restrictions on consumer search rules, the distribution F satisfies familiar properties that are summarized in the next lemma:

Lemma 4:   F is continuous and Supp F = [0, $\Pi^*(I+U/N) - \Pi^*(U/N)$].

Lemma 4 indicates that the advertising distributions have no atoms and no gaps in their supports. In particular, firms do not play pure strategies in any subgames with $N \geq 2$. Further, the support ranges from zero to the level that just exhausts the net gains from capturing the informed consumers with probability one, as opposed to probability zero. [10]

It follows that when an entering firm chooses A and $N \geq 2$ firms have entered, its probability of capturing the informed consumers is $F(A)^{N-1}$; thus, $E(A) = (F(A)^{N-1})I + U/N$ in this context. In order to play a best response, the firm therefore must choose

(11). $Z = Z^*((F(A)^{N-1})I + U/N)$

in conjunction with A. As profits must be constant along the support of F, it must be that when N firms have entered, F is determined by

(12). $\Pi^*((F(A)^{N-1})I + U/N) - A = \Pi^*(U/N)$.

Since the better profit property (Lemma 3) states that Π^* is increasing in E, it follows at once that (12) gives a properly defined distribution function. Intuitively, F(A) is defined so that, along the support of possible advertising levels, the cost of a higher advertising expenditure is

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[10]The arguments in the proof of Lemma 4 are very similar to those used to characterize equilibria in the price dispersion and auction literatures. In the present case, however, restricting off-equilibrium-path consumer responses is crucial to the result, since otherwise there are a great many other symmetric equilibria, including pure-strategy equilibria, that in principle can be supported by the informed consumers' threat to stay away from firms that deviate from their place in the advertising rank-order.

just balanced against the benefit of a greater chance of capturing the informed consumers. Finally, for subgames in which $N = 1$, it is clear that a single entering firm chooses $Z = Z^*(1)$ and $A = 0$, and all consumers visit it.

Next consider the consumer search rules. Since all entering firms use the same strategy in any subgame, it follows that the random search rule is optimal for the uninformed consumers. Further, when $A > A'$ we have $F(A)^{N-1} > F(A')^{N-1}$, and so the better deal property (Corollary 2) gives

$$W^*((F(A)^{N-1})I + U/N) \geq W^*((F(A')^{N-1})I + U/N).$$

In other words, firms that advertise more heavily will offer better deals, as a consequence of their greater expected market share. This in turn ensures that the advertising search rule is optimal for the informed.[11]

Finally, the number of entering firms, denoted by N^A, is determined by the zero profit condition. Since expected profit is constant along the support of the possible advertising levels, we may focus on the case in which a firm selects zero advertising and is sure to capture only the uninformed consumers. Thus, the zero-profit condition may be expressed as

(13). $\qquad U/N^A \geq \bar{E} > U/(N^A + 1)$.

The final inequality in (13) will surely hold for a sufficiently large number of firms. The first inequality might fail for all $N^A \geq 2$, however, in which case we put $N^A = 1$. This completes the proof of:

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[11]As is easily verified, if K and V are intervals and $C_{QK} < 0$, then firms with higher expected market share offer *strictly* better deals, and so utility maximization implies that the informed consumers *must* concentrate search among firms with the highest advertising levels. We show in our 1992 paper that $C_{QQ} < 0$ also suffices for a strict better deal in this model.

<u>Proposition 2</u>:   A symmetric advertising equilibrium exists if and only if:

(a).   If $N \geq 2$, then (12) gives the mixed advertising strategy, and (11) gives the Z choice

that accompanies the advertising level A;

(b).   If $N = 1$, then $Z = Z^*(1)$ and $A = 0$; and

(c).   The equilibrium number of entering firms is given by N^A as defined in (13).

This demonstrates that consumers' sensitivity to ostensibly uninformative advertising may be based on the entirely rational proposition that higher advertising indicates a better deal. Moreover, consumer reliance on simple and easily implemented rules of thumb can emerge from an equilibrium in which the rules are preferred over any other possible search procedures.[12] Note finally that the symmetric advertising equilibrium gives rise to heterogeneity in market structure: firms with large scale, high variety, low prices and high advertising coexist with firms that have small scale, low variety, high prices, and low advertising.[13]

C.   MARKET STRUCTURE, WELFARE AND INFORMATION EXTERNALITIES

It is straightforward to compare symmetric advertising and random equilibria from the standpoints of equilibrium market share and social surplus. Note first that $N^R \geq N^A$, i.e., the

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[12]As we show in our 1992 paper, this conclusion also holds when consumers are allowed to search sequentially at a constant cost per search, in which case an optimal rule for informed consumers is to first search a highest-advertising firm, and then, should additional searches be desired, always search from among those unvisited firms whose advertising level is highest. A novel feature of the sequential-search model is that low-advertising firms are driven to "compete," offering greater consumer welfare than would a monopolist facing the same expected market share; this is because uninformed consumers otherwise would choose to search again, hoping thereby to find a high-advertising, good-deal firm. This additional constraint on firms' choices results in lower profits, and so fewer firms enter; thus, concentration is higher when sequential search is possible.

[13]Persistent differences between firms may be difficult to explain if our mixed-strategy advertising equilibria are repeated period-by-period; however, our equilibria may be purified (see note 9) by supposing that firm's advertising costs vary, and that advertising costs are private information. Persistent differences can then be associated with differences in advertising costs.

symmetric advertising equilibrium is associated with a more concentrated market structure. This result, which follows at once from the free entry conditions (10) and (13), is easily understood. In the random equilibrium, a firm garners its proportionate share $1/N^R$ of the total consumer population. In the symmetric advertising equilibrium, in contrast, a zero-advertising firm can draw only from the uninformed consumer population, and hence its market share is U/N^A. Since $U < 1$ and the firm must earn zero profit in either case, $N^R \geq N^A$ is required. More generally, rivalry for the informed consumers in the symmetric advertising equilibrium serves to dissipate the profits available from capturing them. Thus, there are less profits remaining for any given number of firms, and so fewer firms enter.

Although the symmetric advertising equilibrium encourages greater industry concentration, the social surplus that it generates is at least as high as that found in a random equilibrium. This is clear if $N^A = 1$, since consumers obtain the best possible deal when all purchases are concentrated at a single firm, given that coordination economies are present. Suppose then that $N^A \geq 2$. Note first from (10) and (13) we have $1/N^R \approx U/N^A$. It follows that $Z^*(1/N^R) \approx Z^*(U/N^A)$ and so the better deal property (Corollary 1) gives:

$$(14). \qquad W^*(1/N^R) \approx W^*(U/N^A)$$
$$\leq \int_0^\infty W^*((F(A)^{N^A-1})I+U/N^A)dF(A)$$

where F is the advertising distribution when N^A firms enter.[14] The first term in (14) gives consumer utility in the random equilibrium, which is (approximately) equal to the utility offered in the symmetric advertising equilibrium by a firm that chooses zero advertising. The latter event occurs with probability zero, however, and a consumer will almost surely visit a firm that chooses positive advertising and offers a better deal. The final term in (14) gives the expected utility of an uninformed consumer in the symmetric advertising equilibrium. Informed

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[14]Integrability of W^* in (14) follows from the monotonicity of $W^*((F(A)^{N-1})I + U/N)$ in A.

consumers fare even better, since they are able to locate the best deal from among N^A firms. Since the firms earn (approximately) zero profits in either equilibrium, it follows that social surplus will be no lower in the symmetric advertising equilibrium.[15] Summarizing:

Proposition 3: (a). $N^R \geq N^A$, i.e., concentration is at least as high in the symmetric advertising equilibrium as in the random equilibrium.

(b). Social surplus is at least as high in the symmetric advertising equilibrium as in the random equilibrium.

The key idea is that the informed consumers' sensitivity to advertising, and the ensuing advertising rivalry among firms, operate to improve coordination in the market, both by concentrating purchases at existing firms and by reducing the number of firms. Further, a positive externality arises to the extent that the coordination economies brought forth by the informed consumers are beneficial to the uninformed as well.

These results square nicely with the empirical findings of Benham (1972), Cady (1976), and Luksetich and Lofgreen (1976). As discussed in the Introduction, these authors examined the effects of legal restrictions on advertising activity for the retail eyeglass, prescription drug, and liquor industries, respectively. A prominent conclusion present in all of these analyses, and particularly so in the study by Benham, is that the ability to advertise results in lower prices and greater concentration, even when the advertisements are restricted to convey little or no actual price information. Proposition 3 offers an explanation for these findings. In particular, we may associate the random equilibrium with the outcome that would occur were advertising banned, and we may interpret the advertising equilibrium as a plausible outcome when only "noninformative" advertising is legalized. Our model then predicts that the

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[15]Social surplus is strictly higher in a smoother model; see note 11.

presence of coordination economies leads to lower prices and greater concentration when such advertising is permitted, just as the previous authors found in their industry studies.

The extent of coordination economies achievable through advertising is influenced by the informativeness of advertising, which is reflected here by the proportion of consumers that are informed. In particular, as the proportion I of informed consumers rises, the number of firms does not increase and the social surplus does not decline. Entering firms also advertise more heavily when there are more informed consumers:

Proposition 4: In the symmetric advertising equilibrium, an increase in I leads to:

(a). Entry by the same number or fewer firms;

(b). A first-order shift in the equilibrium advertising distribution toward higher advertising levels;

(c). The same or greater social surplus.

To understand part (a), note that an increase in I is tantamount to a decrease in U. Thus the free-entry condition (13) implies that N^A cannot rise. Part (b) follows from the equal-profits condition (12): since I increases while U/N^A remains (approximately) constant, the probability of capturing the informed consumers at any given A, which is $F(A)^{N^A-1}$, must fall in order to preserve (12). As N^A is nonincreasing in I, it can only be that $F(A)$ declines for each A > 0. Finally, given that entering firms offer (weakly) better deals on average when I increases, it is intuitive that social surplus cannot decline; this intuition is verified in the Appendix.

This result shows that advertising brings about better coordination when it is more informative. Further, consumers who switch from uninformed to informed convey a positive externality on all other consumers. This suggests the intriguing possibility that from a social welfare standpoint, consumers may pay too little attention to advertising.

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III.   DECLINING MARGINAL COSTS

In the preceding analysis, we have made the simplifying assumption that marginal costs are constant. Our results can be extended to incorporate the possibility of declining marginal costs, however. This possibility tends to broaden the scope for coordination economies, since higher market shares then directly reduce marginal costs, and this encourages firms to choose lower prices. Further, declining marginal selling costs are highly salient empirically in retail markets, due to the prevalence of *manufacturer quantity discounts* in these markets. Empirical studies have shown that quantity discounts are a widespread and significant feature of retail markets (Charles Brown and James Medoff, 1990), especially for the retail prescription drug (Cady, 1976) and retail eyeglass (U.S. FTC, 1988, p. 44) markets.

To introduce the possibility of declining marginal costs, we weaken A2 as follows:

<u>A2'</u>:   For each good, there is a twice-continuously-differentiable selling cost function, $C(Q,K)$: $R_+ \times R_+ \to R_+$, satisfying:

i). $C_{QQ} \leq 0$

ii). $C_Q \geq 0 \geq C_{QK}$

iii). $C_K \leq 0$.

Thus, a better selling technology lowers marginal and total selling costs, while greater output also lowers marginal selling costs.

The results of Section I may be verified also to hold under the weaker A2', if a firm faces no uncertainty as to its market share. In this case, $E \equiv M$ and the optimal price satisfies

(15). $D(\tilde{P}) + (\tilde{P} - C_Q(D(\tilde{P})M,K))\ D'(\tilde{P}) = 0$.

We continue to assume A4, so that $\tilde{P}$ is uniquely defined; this is a sensible assumption, provided that marginal costs do not decline too steeply. Inspection of (15) reveals that $\tilde{P}$ is now a function

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of both K and M. Further, it is direct to verify that $\tilde{P}$ is strictly decreasing in M for given K if $C_{QQ} < 0$. Thus, declining marginal costs represent a new source of coordination economies.

To allow for uncertain market shares, let us limit attention to a family $H(M|E)$ of distribution functions parameterized by E, where $H_E(M|E) < 0$ for all M. In addition, let the parameterization be chosen so that

$$E = \int_{M_s}^{M_b} M\,dH(M|E)$$

Therefore E also gives the expected value of M under the distribution $H(M|E)$.[16]

Expected net revenue per product is now given by

$$R(P,K,E) = \int_{M_s}^{M_b} r(P,K,M)\,dH(M|E)$$

where $r(P,K,M)$ is defined in (1). It is straightforward to extend Lemma 1 to the present case: $C_{QK} \leq 0$ ensures that $\tilde{P}$ is non-increasing in K for given E, for any distribution $H(M|E)$. The remaining coordination properties also hold, provided that added restrictions are imposed:

<u>Lemma 5</u>: Assume A1, A2', A3 and A4, and also $C_{QQQ} \geq 0$. If for all E, P and K, we have

(16). $\text{Var}(M|E) \leq E(2M_s - E)$

(17). $\text{Var}(M|E) \leq E(M_s - E) + E / [C_{QQ}(D(P)M_s,K)\, D'(P)]$

then it follows that

(a). $\tilde{P}$ is nonincreasing in E;

(b). $\Pi(K,V,E)$ is supermodular in K, V and E;

(c). $\Pi_E(K,V,E) > 0$.

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[16]Let $G(M|\alpha)$ be any family of distribution functions parameterized by α, with $G_\alpha < 0$. Let $E(\alpha)$ be the expected value of M under distribution $G(M|\alpha)$. Since $E(\alpha)$ is strictly increasing in α, we may define the family $H(M|E)$ by $H(M|E) \equiv G(M|E^{-1}(E))$.

With Lemma 5 at hand, it is a simple matter to confirm that all of the results of Section I continue to hold under the added restrictions listed above. Intuitively, greater expected market share continues to encourage the selection of large variety and better technology; further, lower prices also become more attractive when expected market share rises, since expected marginal selling costs are then reduced, as a consequence of better technology *and* declining marginal selling costs.

The added restrictions are needed to address the possibility that $\tilde{P} < C_Q(D(\tilde{P})M_S,K)$, i.e., the expected-profit-maximizing price lies below marginal costs at the lowest possible market share. In this case, a slight upward shift in the lower tail of the market-share distribution, which would raise E, might *reduce* the firm's expected profits by adding sales only in states of nature in which price lies below marginal costs. Such a shift in the distribution also could lead the firm to raise its expected-profit-maximizing price.[17]

This perverse possibility arises when the market-share distribution places a great deal of weight on levels of M that lie far above M_S, so that marginal costs in low-M outcomes do not figure prominently in expected profits. Conditions (16) and (17) restrict the family $H(M \mid E)$ by requiring that low-M outcomes be given sufficient weight: E must lie close enough to M_S, and the market-share variance must be sufficiently small.[18] Finally, the assumption $C_{QQQ} \geq 0$ is used to simplify the statement of the restrictions on $H(M \mid E)$, and it can be substantially relaxed.[19] Note however that the assumption is reasonable in the case of manufacturer quantity discounts, given that wholesale prices decline by smaller increments as quantity rises.

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[17]Consider the parameterization $D(P) = 2.5(1 - P)$, $C(Q) = 0.75Q -0.25Q^2$ for $Q \leq 1$ (extendable to $Q > 1$ in conformity with A2'), and let M have a two-point distribution with support $\{M_S,M_b\}$. It can be shown that for $M_b = 1$, the expected-profit-maximizing price is strictly increasing in M_S, and maximized expected profits are strictly decreasing in M_S, at $M_S = 0$.

[18]Observe that (16) implies (17) when C_{QQ} is small; (17) can be thought of as an added restriction that is needed in the case of very steeply declining marginal costs.

[19]$C_{QQQ} \geq 0$ may be replaced by $C_{QQ} \in [A,B]$ for all Q,K, where A and B are constants satisfying $A \leq B < 0$. Then Lemma 5 holds if the term $2M_S$ on the right-hand-side of (16) is replaced by $(A+B)M_S/A$, and if the $C_{QQ}D'$ term on the right-hand-side of (17) is replaced by AD'.

It is also important to remark that the results of Section II are completely unaltered under the weaker assumption A2'; in other words, our equilibrium advertising model is fully robust to the possibility of declining marginal costs, whether or not restrictions (16) and (17) hold. This assertation is proved in our 1992 paper.[20]

IV. CONCLUSION

In this paper, we develop an explanation for consumers' responsiveness to ostensibly uninformative advertising in retails markets in which coordination economies are present. The basic idea is simple: when consumers respond to advertising, firms that advertise heavily expect large market share and therefore offer better deals; as a consequence, consumers are entirely rational in responding to uninformative retail advertising. After developing this result at a general level, we turn to a specific equilibrium model of advertising, finding that the ability to advertise leads to a more concentrated market structure and greater social welfare. These results give a theoretical rationale for the empirical findings of Benham and others that link advertising regulations to structural features of retail markets.

Our equilibrium advertising model, while providing a tractable vehicle for the analysis of entry and welfare, has a few features that might strike some as unrealistic or difficult to interpret: observability of the advertising rank-order implies a "winner-take-all" property whereby the advertising leader captures all of the informed consumers, no matter how small its lead; market advertising levels do not affect the proportion of informed consumers; and firms' strategies must be randomized. As we have emphasized, however, our main results do not rely on the particular structure of our equilibrium model, and it is easy to conceive of other models having different features but the same coordinating role for advertising.

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[20]The added restrictions are not needed because firms face two-point distributions of market shares, having only U/N and $I + U/N$ in their supports. In this case, raising E by increasing $I + U/N$ for fixed U/N and $F(A)^N$, or by increasing the probability of $I + U/N$ for fixed support, will raise expected profits and reduce expected-profit-maximizing prices, irrespective of whether (16) or (17) hold. Further, these monotonicity properties suffice for our results in Section II, despite the fact that increasing the lower point in the support may have the perverse effects discussed above and demonstrated in note 17.

As an example, suppose that firms can choose from among only two advertising levels, "high advertising" and "zero advertising."[21] Informed consumers observe advertising, and in advertising equilibria they divide themselves only among the high-advertising firms; high-advertising firms in turn offer better deals since they gain both their share of the uninformed and a portion of the informed. Despite the artificiality of assuming only two advertising levels, this model delivers pure-strategy advertising equilibria in which advertising leaders split the informed consumers, and in which our entry and welfare results hold up. Further, it is simple in this setting to allow the total consumer population and the proportion of informed consumers to rise with total advertising expenditures.

More general and realistic models could combine a continuum of advertising levels with noisy observability by consumers of advertising rank-order. While analyzing equilibria in these cases might prove to be technically involved, it is important to recognize that the general results given above would continue to hold: as long as expected equilibrium market share rises with advertising, consumers have every incentive to seek out the firm that is most likley to have advertised the most, and this in turn facilitates coordination of consumer purchases.

We view advertising as a natural vehicle with which to coordinate consumer purchases, since so many consumers observe major advertising efforts. Advertising is not, however, the only means of coordinating consumer behavior. Reputation also may be a plausible coordinating device, in the sense that a firm with a reputation for large variety and low prices receives a large market share, and this response in turn makes it desirable for the firm to sustain its reputation. Reputation formation may depend on a dynamic process of information transfer via consumer word-of-mouth. Presumably, in such a dynamic setting, zero profits might still emerge, if firms battle in the industry's early phase for the large-variety and low-price reputation. Interesting future work might explore dynamic models, in order to assess the role of advertising expenditures in creating and maintaining such a reputation.

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[21]We thank a referee for suggesting this model.

Proof of Lemma 1: This follows immediately after the observation that $R_{PK} = -c'D'E \leq 0$.

Proof of Lemma 2: Observe that:

(A1). $\Pi_{KE} = VR_{KE} = -Vc'D \geq 0$

(A2). $\Pi_{VE} = R_E = (\tilde{P}(K) - c)D > 0$

(A3). $\Pi_{KV} = R_K - S_{KV} = -c'DE - g' - S_{KV} \geq 0$.

Proof of Lemma 3: Continuity of $\Pi^*(E)$ follows from the Maximum Theorem, since Π is continuous and $K \times V$ is compact. Next, pick $E^1 > E^2$ and observe that:

$$\Pi^*(E^1) \equiv \Pi(K^*(E^1), V^*(E^1), E^1) \geq \Pi(K^*(E^2), V^*(E^2), E^1)$$

$$> \Pi(K^*(E^2), V^*(E^2), E^2) \equiv \Pi^*(E^2),$$

where the first inequality follows from the definition of a maximizer while the final inequality follows since $\Pi_E = V\Pi_{VE} > 0$ by (A2).

Proof of Lemma 4: Suppose first that N firms have entered and that F is discontinuous at A, so that $F(A^-) < F(A^+) = F(A)$. Letting $E(M \mid A)$ represent the expected market share given A, the expected profit obtained when a firm chooses Z and A is given by:

(A4). $VR(P, K, E(M \mid A)) - S(K, V) - A$

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When the firm chooses A, it must in equilibrium choose Z to maximize (A4); using assumption A4, it therefore follows that $P = \tilde{P}(K)$. Further, from assumption A5, we know $V > 0$. Combining these facts and employing (A2), we may conclude that the firm's expected profits are strictly increasing in $E(M \mid A)$. Thus, choosing $A + \varepsilon$ for sufficiently small $\varepsilon > 0$ would assure the firm of strictly greater profits than the maximized value of (A4), and this contradicts $A \in$ Supp F.

Next, put $\underline{A} \equiv$ min Supp F and suppose $\underline{A} > 0$. Since F is continuous, it follows that a firm captures the informed consumers with probability zero when it chooses $A = \underline{A}$. But this continues to be true when it chooses $A = 0$, and profits are strictly higher in the latter case. For $\bar{A} \equiv$ max Supp F, we must have $\Pi^*(I + U/N) - \bar{A} = \Pi^*(U/N)$, since by choosing $A = \bar{A}$ a firm captures the informed with probability one, and profits must be equalized over the support. Finally, suppose there exists $A' \in (0,\bar{A})$ with $A' \notin$ Supp F, and let (x,y) be the largest interval containing A' such that $(x,y) \cap$ Supp $F = \varnothing$. Since $x,y \in$ Supp F and F is continuous, we have:

$$\lim_{A \downarrow x} \Pi^*((F(A)^{N-1})I + U/N) - A = \Pi^*((F(x))^{N-1}I + U/N) - x$$

$$=\Pi^*((F(y))^{N-1}I + U/N) - y = \lim_{A \uparrow y} \Pi^*((F(A))^{N-1}I + U/N) - A.$$

But we have a contradiction since F must be constant on (x,y).

Proof of Proposition 4(c): Recall that N^A is a nonincreasing function of I. The expected utility of uninformed consumers in the symmetric advertising equilibrium may be written:

(A5). $\int_{U/N^A}^{I+U/N^A} W^*(E)dG(E)$

where $G(E)$ is the implied distribution of E, given by

$$G(E) = \text{Prob}\{(F(A)^{N^A-1})I+U/N^A \leq E\} = [(E - U/N^A)/I]^{1/(N^A-1)}.$$

As I rises and U therefore falls, N^A adjusts down to keep U/N^A (approxiamtely) constant; as a consequence, $G(E)$ is decreasing in I, and so the integral above cannot decrease, since $W^*(E)$ is nondecreasing under Corollary 2.

The informed consumers purchase only from the firm that chooses the highest advertising level and thereby anticipates the highest E. Thus their utility may be written

$$\int_{U/N^A}^{I+U/N^A} W^*(E)dG^{N^A}(E)$$

and an increase in I, with the corresponding reduction in N^A, continues to have a nondecreasing effect on utility since $[(E - U/N^A)/I]^{N^A/(N^A-1)}$ is decreasing in I.

Proof of Lemma 5: (a). $\tilde{P}$ is nondecreasing in E if $R_{PE}(\tilde{P},K,E) \le 0$, which in turn follows from $r_{PM}(\tilde{P},K,M) \le 0$ for all M. To show the latter, rearrange the first-order condition $R_P(\tilde{P},K,E) = 0$ to get

$$(A6). \quad D + \tilde{P}D' = (1/E) \int_{M_S}^{M_b} C_Q(DX,K)D'XdH(X|E)$$

where D and D' are evaluated at $\tilde{P}$. Using (A6) then gives

$$(A7). \quad r_{PM}(\tilde{P},K,M) = D + \tilde{P}D' - C_Q(DM,K)D' - C_{QQ}(DM,K)DD'M$$

$$= (D'/E) \int_{M_S}^{M_b} \{C_Q(DX,K)-C_Q(DM,K)- C_{QQ}(DM,K)DM\}XdH(X|E).$$

Under the assumption $C_{QQQ} \ge 0$, we have

$$C_Q(DX,K) - C_Q(DM,K) = \int_M^X C_{QQ}(DY,K)DdY \geq C_{QQ}(DM,K)D(X - M).$$

Plugging this into (A7) gives

$$r_{PM}(\tilde{P},K,M) \leq (D'C_{QQ}(DM,K)D/E) \int_{M_S}^{M_b} (X-2M)XdH(X \mid E).$$

Thus, we have $r_{PM}(\tilde{P},K,M) \leq 0$ if

$$\int_{M_S}^{M_b} (X-2M)XdH(X \mid E) = Var(X \mid E) + E^2 - 2ME \leq 0,$$

which under (16) holds for all $M \geq M_S$.

(b). Observe first that $\Pi_{KV} \geq 0$ holds without imposing (16) or (17). Next, we have that

$$\Pi_{KE} = VR_{KE} + VR_{KP}\frac{\partial \tilde{P}}{\partial E} \geq 0,$$

where $R_{KE} \geq 0$ and $R_{KP} \leq 0$ both follow from $C_{QK} \leq 0$. Finally, $\Pi_{VE} > 0$ if $R_E(\tilde{P},K,E) > 0$, which in turn would follow if $r_M(\tilde{P},K,M) > 0$ for all $M > M_S$. We now show this to be the case. Observe that $C_{QQ} \leq 0$ implies that

$$r_M(\tilde{P},K,M) = (\tilde{P} - C_Q(DM,K))D \geq (\tilde{P} - C_Q(DM_S,K))D,$$

where D and D' are evaluated at $\tilde{P}$. Thus, it suffices to show that $\tilde{P} - C_Q(DM_S,K) \geq 0$. To see this, observe that

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$$\tilde{P} - C_Q(DM_S,K) = -(D/D') + (1/E) \int_{M_S}^{M_b} C_Q(DX,K)XdH(X\,|\,E) - C_Q(DM_S,K)$$

$$= (D/E)[-(E/D') + \int_{M_S}^{M_b} \{ \int_{M_S}^{X} C_{QQ}(DY,K)dY\}XdH(X\,|\,E)]$$

$$\geq (D/E) [-(E/D') + C_{QQ}(DM_S,K) \int_{M_S}^{M_b} (X-M_S)XdH(M\,|\,E) \geq 0,$$

where the first equality uses (A6) to substitute for $\tilde{P}$, the first inequality uses $C_{QQQ} \geq 0$, and the second inequality is implied by (17).

(c). $\Pi_E > 0$ follows immediately from part (b) and assumption A5.

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