1995

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ISSN:0318-725X
ISBN:0-7714-1840-X

RESEARCH REPORT 9523

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August 1995

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Abstract

Whether signaling models of advertising have empirical content has not been established. This paper explores panel data on advertising and product pricing for firms in the compact disc player market over 1983-92. Using what appear to be the most reliable measures of these variables, advertising and price move together, rising for the first two to three years after a player is introduced and falling thereafter. This behavior is inconsistent with formalizations of Nelson's (1974) original signaling model, and partially consistent with the imperfect consumer learning model developed by Horstmann and MacDonald (1994); a modest (adding one period) extension of the latter provides predictions consistent with the observed behavior.

This research was supported by the John M. Olin Foundation. April Franco and Brian Barry provided capable research assistance.

1 Introduction

In 1994 U.S. firms spent more than $53 billion advertising their products and services. While some of this expenditure can be attributed to firms informing consumers about the availability of their products, much of it does not appear to serve any such directly useful purpose. Manufacturers such as Maytag or SONY no longer have to inform consumers of their products' existence; nevertheless, they advertise heavily.[1] That these firms survive despite this seemingly wasteful activity suggests that advertising is, in fact, associated with greater profits. Studies dating back to Bain (1956) (also Commanor and Wilson (1974) and Scherer and Ross (1990)) lend support to this conclusion by finding strong positive correlations between advertising expenditures, prices and profits.

Why, beyond having immediate informational value, should advertising enhance profitability? Many explanations have been put forward; however, the most thoroughly articulated traces to Nelson (1974). Nelson suggested that advertising could serve a signaling role in situations in which consumers are badly informed about product characteristics prior to purchase. He argued that advertising could signal which products are "better buys" in that firms producing such products would find advertising to have higher returns and so would do more of it. Consumers could then base purchase decisions on the volume of advertising as a rational response to the advertising signal. In doing so, they would confirm the value

[1] In 1994, for instance, according to *Leading National Advertisers*, the Maytag Company spent $57 million on advertising, while SONY advertised to the tune of $331 million.

of increased advertising. The empirical relation between advertising and profitability then follows from the equilibrium facts that better buys advertise more heavily as a consequence of their being better buys and that advertising attracts more customers as a consequence of their having correctly inferred this fact.

Following Nelson, the signaling explanation for advertising has received numerous formalizations; most prominent are Kihlstrom and Riordan (1984) and Milgrom and Roberts (1986). The models distinguish between advertising that is informative, in that it conveys verifiable information on the product's existence, function, location of sale, etc. and advertising that is purely dissipative and serves as a means of signaling quality. Signaling equilibria exist in which producers of newly-introduced, high-quality products engage in wasteful advertising while producers of newly-introduced, low-quality products do not (In what follows, such equilibria are referred to as "Nelson equilibria".) No wasteful advertising is undertaken once the product has become established, and product price is either constant or rising over time (both for the low- and high-quality products), with price always higher for the high-quality product.

These features of Nelson equilibria imply a number of predictions about both the contemporaneous and time series behavior of the endogenous variables. In particular, *i) contemporaneous price and quality are positively correlated at any time, and both are positively correlated with advertising expenditures when the product is introduced; ii) the time path of price (and also expected price) is non-decreasing; iii) for advertised products, the time path of advertising expenditures is declining; and iv) the time series of price and advertising*

expenditures are negatively correlated.[2]

The structure of Nelson equilibria and, therefore, their predictions, depend on an important assumption; namely, that consumers learn *all* relevant information about the product in question from their introductory-period consumption experience. That is, the information value of advertising high-quality products in the introductory period arises because introductory consumption experience exposes a firm having a low-quality product for sale, causing such a firm to have lower future sales in comparison to a firm with a high-quality product. The consequence of these reduced sales is that the gains the firm might achieve by advertising a low-quality product in the introductory period are too small to offset the advertising cost; the opposite is true should the firm have a high-quality product. The implications listed above follow.

The assumption that a single consumption experience reveals quality to consumers seems problematic, not only on a priori grounds– it is hard to think of a compelling example– but also because it results in no wasteful advertising for established products. There are many examples that, at a minimum, have the appearance of sharply contradicting this prediction. One way to proceed within the context of a signaling framework is to retain the assumption about consumption experience but modify other aspects of the model so that wasteful advertising persists. For example, either entry of new consumers over time or potential "shocks" to quality can be included. Under what precise conditions these sorts of variations would generate wasteful advertising for established products and what effect they

[2] Here "advertising" refers to expenditures beyond what would be required simply to convey information on the product's existence, availability,...

would have on other of the models' results is not known.

Alternatively, consumption experience can be assumed to be an imperfect signal of quality. This approach is explored by Horstmann and MacDonald (HM, 1994). Then, in equilibrium, firms do not engage in wasteful advertising when introducing a product but may do so after the product is established. Further, both producers of high- and low-quality established products may employ wasteful advertising; however, because a producer of a high-quality product is more likely to advertise, doing so acts as an signal of quality, but an imperfect one. In contrast to predictions based on the Nelson equilibrium– *i) contemporaneous advertising expenditures, quality and price are positively correlated for established products, but are otherwise uncorrelated; ii) the time path of average price may be either increasing or decreasing; iii) the time path of advertising expenditures is non-decreasing, iv) the time paths of price and advertising expenditures are positively correlated.*

As is obvious, finding a model in which apparently wasteful advertising is profit enhancing is not problematic– there are several models that predict wasteful advertising in some stage of the product life cycle as a profit-maximizing outcome. Furthermore, these models can be distinguished empirically since, depending on the assumed informativeness of consumption experience, they make different predictions regarding both the stage in the product life cycle at which wasteful advertising is predicted to be observed and the nature of the co-movements of price, profits and advertising expenditures. The purpose of this paper is to investigate the informativeness of these models by asking whether any are consistent with some data and, if not, what modifications are indicated (including, possibly, an entirely new theory).

This paper is not the first to assess advertising-signaling models empirically. Previous studies (e.g., Davis, Kay and Star (1991), Moorthy and Zhao (1995), Tellis and Fornell (1988) and Archibald, Haulman and Moody (1983)) have attempted to measure directly the signal-conveying character of advertising by trying to determine whether producers of high-quality products advertise more heavily than do producers of low-quality products. These authors' use cross-sectional data to calculate correlations between some measure of a product's quality– for instance, quality rankings from *Consumer Reports* or derived from business/consumer surveys– and expenditures on advertising of the product. Overall there is evidence of a weak but positive correlation between advertising expenditures and quality.

Attempts to explore the advertising-signaling hypothesis in this fashion face four problems. The first is the measurement of quality. According to the theory, quality is anything consumers are willing to pay for, including hard-to-measure entities such as "tasty". Construction of an objective measure of quality is difficult at best. Second, if the investigator is able to construct objective, relevant, measures of quality from a publication like *Consumer Reports*, then so presumably can the consumer. In this case, the need for the firm to signal quality is greatly reduced as consumers have an alternative, direct source of quality information.[3] Further, these studies measure advertising as total advertising expenditures and examine cross-sectional variation in total advertising expenditure and quality. Proceeding this way introduces mis-measurement in that the signaling hypothesis refers only to a

[3] One study that avoids this problem is Archibald, Haulman and Moody, who make use of information on quality that was not available to consumers when they made their purchase decision. There is evidence of positive correlation between advertising and quality; however, the correlation is stronger once the quality information was made available to consumers.

positive correlation between quality and wasteful advertising, not total advertising. Finally, to the extent that there are unmeasured differences across firms (size, product age or potential customer characteristics,...), it is difficult to determine whether a positive cross-sectional price-advertising relation is the result of advertising signaling quality or of advertising and price both being related to some unobserved firm characteristic other than quality.

The approach taken here differs from these earlier works in two important respects. First, it makes no attempt to quantify quality, instead treating quality as inherently unobservable and deriving implications for pricing and advertising. Second, it avoids the confounding effects of unobserved differences across firms by focusing on the temporal behavior of price and advertising; that is, the data are a "panel" of firms. The benefit of proceeding in this way is that the aforementioned problems (apart from the issue of what part of advertising is informational, which still must be addressed) do not arise. The cost is that it is not possible to confront the predictions involving quality; instead, attention can only be directed to the behavior of price and advertising.

The data include observations on advertising, prices and product characteristics for firms producing compact disc players for sale in the U.S. between 1983 until 1992. Reasons for this choice are explained below. After removing price differences that are explained by observable features of the product (i.e. the theory takes observable product characteristics, and price variation based on them, as given an explains any other price variation), the intertemporal behavior of price and advertising are determined for each firm, with measures of advertising based on ad space in a leading audio magazine. The robust result is that price and advertising

rise together for between two and three years after the product is introduced and then decline together, reaching their original level after about five years. This is not a calendar time effect since products and firms enter throughout the sample period. Since the Nelson equilibrium implies that price and advertising should move in opposite directions, the observed finding is difficult to interpret in the context of that model. The results are partially consistent with the HM model in the sense that if the period during which consumer's face some uncertainty about product quality (two periods in the model) is two or three years, the price and advertising paths are just what the theory predicts. However, as presently formulated, the theory is inconsistent with the subsequent downturn of price and advertising. A three-period extension of the HM model is able to generate time series more in accord with the data. This extension is discussed below.

The next section describes a simple framework within which the predictions of both the Nelson, Milgrom-Roberts, Kihlstrom-Riordan approach and that of HM can be derived. The third section presents the data, while a fourth section provides details of the empirical analysis and a discussion of the results, including the extension of HM to three periods. The final section concludes.

2 Theories

Signaling models of advertising differ in various ways; however, the essentials of the models and their predictions can be captured by the simple framework to follow, closely related to HM.

Advertising as a Signal of Product Quality:
Compact Disc Players

A firm produces a quality differentiated product at each of two dates: $t = 0$ and $t = 1$. Each consumer purchases either one or zero units of the product in any period. The quality (q) of the product is exogenously determined once-for-all at $t = 0$: quality is "high", $q = h$, with probability δ and otherwise is "low", $q = l$.

Quality is known to the firm before it makes any price or advertising decisions. By contrast, all information on quality available to consumers prior to purchase (other than inferences they draw from firm behavior) is captured by δ. In Nelson's terminology, the good is an "experience" good. Additional information on product quality accumulates through consumption experience: a high-quality good delivers utility (measured in dollars) $u = 1$ with probability ψ_h and utility $u = v$ otherwise, where $0 < v < 1$; a low-quality good delivers $u = 1$ with probability $\psi_l < \psi_h$ and $u = v$ otherwise. Quite simply, consumer information evolves over time, with the quality of the information created by consumption related to the difference $\psi_h - \psi_l$. When this difference is equal to 1, consumption reveals quality perfectly; otherwise, consumption is a noisy signal of quality.[4]

At each date, the firm chooses a price, p_t, and a level of "wasteful" advertising expenditure, a_t, that can take one of two values: $a_t = 0$ (the "no advertising" case) and $a_t = \alpha > 0$ (the "advertising" case).[5] Consumers observe p_t and a_t, and then use this information, in conjunction with any consumption experience, to make a purchase decision at each date.

[4] It is implicit that an individual's consumption experience is private information. In this case outcome-contingent pricing schemes such as warrantees can be ignored. Of course, many products, including the compact disc players in the data studied here, are sold with warranties. However, these warranties do not guarantee all aspects of consumption, such as "works well with the rest of my equipment," or "sounds good to me."

[5] An advertising expenditure is "wasteful" if it does not directly enhance demand for the firm's product. Milgrom and Roberts provide an helpful discussion of this issue.

Payoffs assume the firm and consumers to be risk neutral. Also, the firm produces at constant marginal cost that is independent of quality and set to zero for simplicity. Marginal cost not varying with quality means that any signaling must rely on the differential consumption experience faced by producers of low- versus high-quality products (the original Nelson hypothesis) and not be the result of exogenous cost differentials.

Within this framework, the original signaling model specification would have $\psi_h = 1$ and $\psi_l = 0$. That is, initial-period consumption experience provides consumers with all relevant information about product characteristics/quality. The Nelson equilibrium is a separating equilibrium whose outcome at $t = 1$ is always $a_1 = 0$ (i.e. no wasteful advertising, since consumption at $t = 0$ reveals quality and further signaling is unnecessary) and price of $p_1 = \psi_h + (1 - \psi_h)v \equiv \mu_h$, if $q = h$ and, if $q = l$, $p_1 = \psi_l + (1 - \psi_l)v \equiv \mu_l$. These prices are the expected utilities when the product is known to be high-quality and low-quality respectively, and are the largest amounts the consumer is willing to pay at $t = 1$ given initial-period consumption experience. The outcome at $t = 0$ involves the firm choosing $a_0 = \alpha$ if $q = h$ and $a_0 = 0$ if $q = l$. Price is set at $p_0 = \mu_l$ if $q = l$, while, for $q = h$, price is given by the condition[6]

$$p_0 - \alpha + \mu_l = 2\mu_l. \tag{1}$$

This condition guarantees that, when $q = l$, the firm (weakly) prefers to set price to μ_l and not advertise (reveal its quality as l and obtain two-period profits of $2\mu_l$) rather than

[6] The measure of consumers is set equal to 1 for ease of notation.

claim to have quality h by advertising and setting the price associated with $q = h$ (yielding two-period profits given by the left-hand side of (1)). As long as $\alpha < \mu_h - \mu_l$, (1) implies that $p_0 < p_1 = \mu_h$ when $q = h$.

The predictions for the standard signaling model listed in the Introduction follow easily. In particular, note that price and advertising expenditures are higher in the initial period when $q = h$ than when $q = l$. This fact gives the first prediction that contemporaneous price and advertising expenditures are positively correlated with quality for newly introduced products. Next, both price and advertising expenditures are constant over time for the low-quality product, while price is rising and advertising expenditures falling for the high-quality product. This implies predictions ii), iii) and iv).

The HM version of the model specifies both ψ_h and ψ_l strictly between 0 and 1. An immediate implication of this specification is that, after an initial consumption experience, consumers will not know whether the product they might consume at $t = 1$ is a high- or low-quality one unless firm behavior has revealed quality. The possibility that consumer uncertainty might persist– absent in the original version– is the basis for advertising being a signaling device for established products.

A second implication is that any price/advertising combination that signals quality fully at $t = 0$ implies consumer beliefs about quality that cannot be contradicted by consumption experience; that is, since a bad consumption experience can occur whether $q = h$ or $q = l$,the information value of experience can be swamped by signaling behavior. As a result, should the firm attempt to signal $q = h$ in the introductory period via either price or advertising,

the signal is so easily mimicked if $q = l$ that it never pays to signal at $t = 0$. More precisely, any price/advertising policy adopted by the firm if $q = h$ can be mimicked when $q = l$ in a way that results in the same firm payoff irrespective of quality. It follows that, if there is a separating equilibrium analogous to the Nelson equilibrium, firm profit must be independent of quality and equal to that when q is known to be l: $2\mu_l$. Were the firm to make a higher profit when $q = h$, there would be no incentive for it to reveal quality as low when $q = l$. Rather, it would mimic the strategy associated with high quality, thereby destroying the signaling equilibrium. Profit equal to $2\mu_l$ is the lowest achievable in any equilibrium so that the separating equilibrium is payoff-dominated for the firm by all other equilibria. This fact makes the separating equilibrium an unlikely candidate as a description of firm behavior and subject to elimination via equilibrium refinements.

The equilibrium identified by HM is one in which no signaling occurs for newly introduced products and price is set equal to expected utility. That is, at $t = 0$, $a_0 = 0$ and $p_0 = \delta\mu_h + (1 - \delta)\mu_l$ both when $q = h$ and $q = l$. At $t = 1$, there are two possible equilibrium outcomes. One again involves no signaling, with price lower than at $t = 0$ so that those consumers having the bad consumption experience continue to buy. The other outcome has the firm setting $a_1 = \alpha$ and $p_1 = (\mu_l + \alpha)/\psi_l$ when $q = h$ and, when $q = l$, randomizing between the policy for $q = h$, and setting $a_1 = 0$ and $p_1 = \mu_l$. The randomization is such that only those consumers obtaining the favorable consumption outcome at $t = 0$ purchase at the high price. Advertising for established products is possible because the consumer heterogeneity created by consumption experience at $t = 0$ makes mimicry less rewarding

when $q = l$ (the firm only obtaining a fraction ψ_l of customers rather than the ψ_h obtained when $q = h$) than it was at $t = 0$ when there was no consumer heterogeneity. Advertising occurs because consumer uncertainty persists beyond the initial period. In this equilibrium, advertising signals quality for an established product but does not do so perfectly.

The predictions presented in the Introduction assume that the equilibrium outcome at $t = 1$ is the one above in which advertising is observed.[7] There, contemporaneous price and advertising expenditure are positively correlated with quality (although not perfectly so) for established products (prediction i) in the Introduction). Also, advertising expenditures are rising over time when $q = h$ and rising in expectation when $q = l$, giving prediction iii). While it is not immediately apparent from the above, it is also the case that, if advertising occurs in equilibrium at $t = 1$, it must be that the p_1 associated with $q = h$ is higher than the common price at $t = 0$, p_0. This result implies that the time paths of price and advertising expenditures are positively correlated, prediction iv). Finally, the previous argument implies that price is rising when $q = h$ and, depending on the randomization, may be either rising or falling on average when $q = l$. It can be shown that, overall, average price may either rise or decline in equilibrium: prediction iv).

3 Data

All data were collected from monthly issues of *Audio* Magazine between July 1983 and June 1993; thus, the 1983 figures refer to July 1983-June 1984, and 1992 is the last year of data

[7] Further, the predictions are for equilibrium outcomes satisfying the equilibrium refinement conditions imposed in HM.

available. *Audio*, published by Hachette Magazine, is a leading U.S. publication whose focus is audio equipment.[8]

The October issue of *Audio* includes a (virtually exhaustive) listing of audio components available in the U.S. For each component, the manufacturer's suggested retail price is provided, along with a standardized collection of product characteristics.

The data studied here refer to compact disc players. There are a number of reasons for this choice. One is the availability of the pricing and characteristics information for a broad range of models and firms. The other is that 1983 is the first year that compact disc players were available to consumers. Thus there were no previous generations of the same product from which consumers might have gained experience. Moreover, the laser and error correction technology employed in compact disc players were also new to consumer products, in which case the fact that SONY made good quality television sets prior to 1983 is not necessarily informative about what can be expected from a SONY compact disc player. Of course, it is the case that consumers might view the reliability of the products of an established producer, or the producer's commitment to its warranty, differently in comparison to the way it views a new producer. This is one factor supporting the time series nature of the analysis below; i.e. much of the cross sectional variation in the data may be due to inter-firm variation in the relevance or duration of prior consumer experience.

[8] *Stereo Review*, also a Hachette publication, has a larger circulation than *Audio* (about 500,000, versus about 150,000), but is usually considered to serve a different market– "audio"– including video equipment, televisions, car stereo, and reviews of both audio and video software of various formats. *Audio*, although it is a consumer magazine (as opposed to professional or trade publication), is referred to as serving the "sound engineering" market because its sole focus is audio. It appears that advertising space in *Audio* and *Stereo Review*, both being published by Hachette, are highly correlated, possibly due to its being sold in bundles. In this case focus on *Audio* likely captures much of the variation in advertising in *Stereo Review* as well.

The analysis of prices and advertising studies annual data; i.e. it assumes that a *period* in the *model* is a *year* in the *data*. Practical aspects of the audio component market suggest that a period should be at least one model year, and perhaps longer. The fact that models (even those involving only cosmetic changes) are not introduced more frequently than once a year supports the supposition. Further, if the "true" period is more than one year, then an examination of annual data makes detection of the temporal phenomena of interest more difficult than if data based on the true, but unknown, longer period were examined. In this sense, confirmations of model predictions are robust to period specification.

3.1 Prices and Product Characteristics

The information gathered from the October listing of products included 2369 observations on a total of 1801 models produced by 181 firms. Two conditions were imposed on the sample. The first is that the characteristics data be complete; this reduced the sample to 1700.[9] Second, in 1983 and 1984 a total of four models had prices of $4000 or greater. The pricing of these four models appears to be very different from the pricing of other sixty-six models in those years (for example, the next most expensive model was just $1600) and since there are too few observations to develop a separate analysis for high-end models for those years, these models were excluded. This problem did not arise in the post-1984 data. In the end the pricing data included 1696 observations on 137 firms.

The variables included in the analysis are:[10]

[9] There was no discernable pattern in the absence of product charactersics.
[10] The oversampling rate, OSRATE, is an important characteristic. It was not recorded at all prior to 1985, and for only two players during that year. It was not recorded again until 1987, and during both that year and 1992 it was available for all players. For 1988-1991 there were a few players for which it was not recorded;

- PRICE– Manufacturer's suggested retail price;
- BITS– Number of bits used in the decoding system;[11]
- OSRATE – Oversampling rate used in the decoding system;
- FREHI– Upper limit of frequency response (kHz);
- FRELO– Lower limit of frequency response (Hz);
- SNRATIO– Signal to noise ratio (-db);
- THD– Total Harmonic Distortion (%);
- WEIGHT– Weight (pounds);
- MASH– A dummy equal to one for players utilizing "MASH" technology; and
- LIGHT– A dummy variable equal to one for players weighing strictly less than five pounds.

The table following provides descriptive statistics (Mean/Standard Deviation).

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the analysis of pricing during years where OSRATE is reported for some players and not others includes a dummy variable for players for which the OSRATE is reported. MASH technology came on the scene in 1989, and is therefore included only for 1989 onward; BITS≡ 1 for MASH players. FREHI was available in every year but did not vary across players in 1983, 1984, 1986 and 1989, and was omitted from the analysis for those years.

[11]The figures on BITS in the Table below refer to non-MASH players only, since Mash players all have BITS≡1.

	#	PRICE	BITS	OSRATE	FREHI	FRELO	SNRATIO
1983	24	1026.0	15.60	–	–	11.6	90.84
		186.0	.817	–	–	7.74	1.82
1984	45	1025.96	15.64	–	–	9.09	94.36
		1220.94	.773	–	–	7.06	3.40
1985	84	626.98	15.74	–	19.98	8.39	94.93
		376.94	.679	–	.218	8.45	3.66
1986	145	627.70	15.76	–	–	6.10	96.06
		690.27	.646	–	–	5.31	4.49
1987	183	729.69	15.91	2.63	19.95	5.68	97.50
		833.95	.577	1.13	.410	5.36	6.40
1988	253	856.64	16.15	3.32	19.99	7.30	99.25
		1037.23	.609	1.65	.089	6.84	7.06
1989	225	902.2	16.57	5.30	–	7.17	101.26
		1421.91	1.05	4.77	–	7.14	7.41
1990	259	907.05	17.22	26.22	20.002	7.85	101.65
		1477.88	2.41	103.91	.031	7.79	7.92
1991	246	993.83	19.22	64.06	20.08	7.70	103.27
		1232.67	20.11	127.87	.519	7.77	7.39
1992	235	1282.96	17,79	48.21	20.08	11.46	103.42
		1882.72	1.66	99.91	.454	8.46	8.08

	THD	WEIGHT	MASH	LIGHT
1983	.0058	18.12	–	–
	.0054	4.96	–	–
1984	.0046	18.76	–	–
	.0026	17.27	–	–
1985	.0093	14.45	–	.023
	.0305	7.86	–	.153
1986	.0094	12.69	–	.055
	.0422	9.67	–	.229
1987	.0085	12.90	–	.055
	.0133	8.92	–	.227
1988	.0121	14.13	–	.067
	.0185	11.04	–	.251
1989	.0117	14.63	.009	.04
	.0180	11.16	.094	.196
1990	.0136	14.54	.104	.046
	.0185	10.57	.306	.211
1991	.0110	14.84	.415	.045
	.0193	8.80	.493	.207
1992	.0178	15.84	.443	.051
	.0408	14.29	.498	.221

3.2 Advertising

The advertising data are problematic in the sense that the appropriate empirical counterpart to the theoretical advertising notion is unclear. The theory defines advertising to be any expenditures that do not contribute directly to the design, production or distribution of the firm's product. This definition would exclude expenditures on ads, or parts of ads, that serve merely to inform customers of the features or availability of the product, but would include expenditures such as the firm's support for shows on PBS, or those that ensure prominent display of the firm's logo at sports events or in movies.

In the case of audio equipment, magazines are the primary vehicle through which brands (as opposed to stores, which rely heavily on radio and newspaper advertising) are advertised. Also, with the exception of SONY, which has product lines distinct from audio equipment, most manufacturers of audio equipment are smaller firms that do not engage in significant non-production/distribution expenditures apart from advertising. Thus it is reasonable to assume that advertising in the leading magazines makes up a large part of total advertising. Even if such is not the case, for the time series analysis that follows, all that need be assumed is that advertising in *Audio* makes up a stable fraction of total advertising.

The advertising figures employed here are square inches of advertising space, where the ad makes some reference to a compact disc player available from the firm. Thus an ad that simply displays the firm's name would be excluded, while another that displays the firm's name and mentions that it offers disc players would be included; if other audio products (amplifiers, speakers, tape or cassette recorders,...) are mentioned, the advertising figure

reflects the disc player's proportionate share.

Four points are noteworthy. First, the data are quantities and not dollar values. Data on advertising rates are not available over time; but at the same time there is no indication that the real per page rate (currently $11,315) has varied significantly either.

Second, nearly all firms have multiple models and specific advertising reference to a particular model is virtually nonexistent. Thus the ad data refer to firms, not models, and it is assumed that the unobservable component of quality of successive models does not vary over time for a given firm.[12]

Third, there are numerous potential sources of measurement error in the advertising data. For example, is the fraction of its ads that the firm places in *Audio* stable as assumed? How appropriate is the procedure of allocating advertising space proportionally when more than one piece of equipment appears? Is space all that is relevant, or do other things such as proximity to product reviews matter? In the calculations reported below efforts to confront the measurement error problem are undertaken.

Finally, there is the issue of what fraction of any ad is "informational" and what part might be considered to be "signaling." Many ads contain text, but it is difficult to find any that contain specific information on either features or availability. This sort of information is primarily provided either by retailers or the listing of standardized features in the October issue of *Audio*. In addition, a large fraction of all advertising is found in the October issue, making an ad's value as information even more questionable. For these reasons, it

[12]Since ads refer to firms and not models, the information on pricing of models must be aggregated. Details on how this is done are provided below.

seems most appropriate to interpret whatever text appears in the ads as part of signaling expenditure. Doing so, however, is not wholly without problems. In particular, the results discussed below differ little whether advertising is total or non-text only. This outcome is consistent with the signaling interpretation if text is uninformative, and inspection of the text suggests this interpretation is a reasonable one. If, however, text it is actually informative, then something other than signaling is driving at least that part of the observed association between advertising and prices. Nonetheless, for the present discussion "advertising" will refer to total square inches.

The advertising data are also greatly influenced by scale effects– i.e. large firms such as SONY and Pioneer advertise in volume whenever they advertise. This scale problem has to be taken into account. Since data on firm size (no matter how measured) for the required duration is unavailable for most of the firms in the sample, the most straightforward way to confront the size issue is to adopt a "normalization". Two normalizations were employed. The first treats advertising as a "yes or no" decision and tries to explain the experience profile of the dummy variable describing whether the firm advertised in a given year. The second approach focuses on advertising relative to the average amount of advertising the firm is observed to undertake.[13]

The first approach suffers from the fact that it ignores information on how much the firm advertises whenever advertising is observed. It is unclear *a priori* whether doing so is harmful and depends on the degree of confidence about the information contained in the actual *level* of advertising. If the data are seriously error-ridden, as they may well be, then the first

[13]This measure is defined to be zero for firms that do not advertise at all during the sample period.

approach should be expected to perform better since it ignores all but gross movements in the advertising data, performing much like an "instrumental variable". The results for the first approach are discussed in detail– these results are most robust and statistically significant. The general features of the results employing the second approach are similar, but the greater volatility of the advertising measure causes them to be less clear and robust; some discussion is provided below.

It is hard to provide useful descriptive statistics on advertising. For any given firm, the time series of advertising typically varies significantly and, given the length (at most a decade, and usually much less) of the time series on a given firm, it is hard to discern much about its behavior simply by inspection. (The analysis below follows firms over time and then addresses the shortness of the time series by looking at a cross section of time series.) Nevertheless, the following general properties are apparent in the advertising data. In any year, firms producing roughly half of the models advertise, where the identity of the firms doing the advertising varies over time. Among those models that are advertised, the distribution is spread with surprising uniformity, from twenty-five square inches (a small ad in one issue) to about a thousand (a full page in each issue).

3.3 Removing Price Variation Due to Differences in Observable Characteristics

The theory refers to price differences across products whose observable features are the same. Thus, the first step in the analysis involves removing price differences that are generated simply by differences in observables.

Some initial experimentation with functional form revealed that the empirical relation between price and product characteristics is well described by a relation in which the natural logarithm of price is the dependent variable, and characteristics enter in "levels". Moreover, in agreement with the rapid evolution of product characteristics evident in the table of descriptive statistics, the empirical relation changes significantly from one year to the next. For example, early in the sample heavier players were more immune to vibration and so weight commanded a premium; later, heavier meant "old design". Ultimately, in order to avoid introducing time series characteristics into the unexplained part of the price data by mis-specifying the manner in which it changes over time, a separate price-characteristics relation was estimated for each year. In these regressions the magnitudes of the estimated coefficients vary significantly from year to year, suggesting that use of a "flexible" method is prudent; R^2 varies from roughly .5 to .75.

The price-characteristics regressions imply a predicted log price for each player in each year in which it was offered for sale, the difference from the log of suggested retail price being the unexplained part, which is zero on average in any year. Thus the time series relation between advertising and unexplained price below is, by construction, not a product of similar trends in prices and advertising. Indeed to the extent that signaling behavior is "bunched" near the early part of the sample period, the signaling behavior itself creates trends that are excluded from the analysis here; thus any relations found below should be interpreted as above and beyond the relations implied by signaling that is bunched.[14]

[14]By adopting a less flexible approach to the price-characteristics relation it may be possibile to identify pride-ads relations induced by bunching of signalling behavior. The temporal variation in the implicit prices of characterisitcs, coupled with the relatively rapid evolution of "typical" features, suggest that it weould be

The calculations that follow focus on the unexplained part of log price normalized by the standard error of the forecast of log price. There are two reasons for introducing this normalization. One is simply that the precision in the price-characteristics estimation varies by year. Thus, even if the "true" unexplained part of price were to remain constant over time, without the normalization there is time series variation in the unexplained part of price, which operates like additional measurement error when estimating the time series relation between advertising and unexplained price. Second, even within a given year, if one player has characteristics that are more extreme than another, it is likely that the unexplained part of price will be larger in absolute value, simply as a result of imprecision in the estimation of the price-characteristics equation. This also has the effect of introducing additional measurement error.

In all that follows, "price" refers to the unexplained portion of log price, normalized by the standard error of the prediction.

3.4 Aggregation of Prices

The prices are calculated for each model and year of availability. The advertising data are available by firm, where each firm most often offers more than one model. It follows that some sort of aggregation of unexplained prices is required. The approach adopted here is simply, for each firm, to average across all models.[15] Having done so, the available data are a time series of both unexplained prices and advertising, where the length of the time series

difficult to estimate this with much confidence.

[15]The analysis was also carried out using the average of the maximum and the minimum prices, as well as the median. The overall results are insensitive to the method of aggregation.

is equal to the number of years during which the firm had a product for sale. Altogether there are 559 firm-years of data on 137 firms.

4 Analysis

If the signaling framework is employed to interpret these data, there are four hypotheses that can be investigated. The separating equilibrium studied by Nelson predicts that price will rise over time, advertising will fall, and price and advertising will be negatively correlated. The HM analysis does not restrict the time path of price, and predicts that advertising will rise over time and that advertising and price will be positively correlated over time. These hypotheses are investigated in turn.

To accord with the theory, time is measured in what follows not as calendar time but as years since the product first appears in the data (EXPER, in the figures that follow).[16] Thus "time path" is replaced by "experience profile." Furthermore, *all* regressions include a fixed effect for each firm (i.e. a dummy variable for each firm) to prevent cross section variation in unobservables from influencing the analysis. Implementing this procedure requires that at least two observations on each firm, thereby reducing the number of observations by 34, to 525.[17]

[16]Recall that by construction, the time path of prices, prior to aggregation, has no trend in calendar time. The aggregated price series has a small positive trend.

[17]Alternatively, estimation can be conducted on the full sample. However, firms on which there is but one observation make no contribution to identification of the form of the experience profiles.

4.1 Experience Profile of Price

To investigate the shape of the experience profile of price, a regression of price on EXPER was calculated. The Ramsay reset test applied to the simple regression gave a strong indication ($F = 5.22$, with prob. value .006) that the relation between price and EXPER is nonlinear, prompting the adoption of a quadratic specification; no further indications of nonlinearity were found. The coefficients of $EXPER$ and $EXPER^2$ in this regression are .059 ($t = 1.92$) and -.012 (t =3.05); $R^2 = .67$. Since $EXPER$ is defined to be zero during the firm's first year offering its product, these estimates imply that price increases with the duration of consumer experience with the product for roughly the first two and a half years (i.e. $.059/(2 \times .012)$) of the product's time in the market and decreases thereafter.

The interpretation of this result, both within the original signaling framework as well as the Horstmann/MacDonald framework is that the signaling models are relevant for two or three years (together making up the two periods in the model), in that the observed behavior is consistent with the predicted price paths for both sorts of models. Neither model predicts the observed decline in prices that occurs after three years, although, as discussed below, a three-period version of the Horstmann/MacDonald model can provide a partial explanation of this phenomenon.[18]

[18]A potential explanation for the declining part of the price profile is that it is simply a "sample attrition" effect– firms leave the sample because their price is high relative to what would be expected on the basis of product characteristics. In that case the group of firms who survive longer must have a lower average price. This explanation appears to be incorrect. When the calculations are repeated for only those firms that would eventually have six or more years of experience, the results are very similar.

A second possible explanation for the declining part follows from the observation that since the first year in the data in 1983, observations of long experience necessarily correspond to the early 1990's, in which the slow pace of economic activity at that time would have been expected to generate weak demand, and thus falling prices, for consumer durables such as compact disc players. This explanation is incorrect for two reasons. First, by construction, the price data (prior to aggregation) are effectively detrended. And second,

4.2 Experience Profile of Advertising

The experience profile of advertising (measured by the advertising dummy) is strikingly similar to the profile of price. Estimation of the linear probability model yields clear evidence of nonlinearity that is well described by a quadratic. The coefficients of $EXPER$ and $EXPER^2$ are .025 ($t = 1.41$) and -.0063 ($t = 2.80$); $R^2 = .556$. These estimates imply that the probability of advertising is rising for about two years (i.e. .0252/(2×.0063) and falling thereafter.

This finding can be given several interpretations within the signaling framework. The Nelson model must interpret the results as advertising being high during the introductory period and low thereafter, once consumers have gained experience with the product. This explanation demands that the "introductory" period *for a given product* be very long in the sense that advertising doesn't even begin to decline until a product has been on the market for over two years. It is not until the product has been on the market for more than four years that advertising is estimated actually to fall below initial levels.

This definition of introductory period poses a problem for the interpretation of pricing behavior, however, as price, rather than rising, is estimated to be falling by year three and, by year five, to have fallen below the price at which the product was first introduced. If the average price over the first four years is defined to be the model's "introductory" price, the data have price falling between the introductory and post-introductory periods, not rising, as the model predicts.

inclusion of real GDP growth in the regression has very little impact.

Within the HM framework, the interpretation is of a much shorter introductory period, leading to a rise in advertising over the first two or three years of a product's life. This interpretation is consistent with the interpretation of the price path. As before, however, the model fails to pick-up the decline in advertising starting in year three. Again, a three-period version of the model seems to be able to provide a partial explanation for the downturn.[19]

4.3 Price–Advertising Relation

Given the results of the previous two subsections, it can be anticipated that price and advertising should move together as consumer experience with the product unfolds. This is indeed the case, in that a fixed effects regression of price on advertising yields a coefficient of .159 ($t = 2.13$) with $R^2 = .62$. Again, however, this positive correlation includes declining price and advertising paths for more established products, a phenomenon at odds with both models.

4.4 Discussion

When advertising is measured as a dummy variable, the results indicate that while an introductory period defined to be approximately the first four years of a product's life makes the Nelson model consistent with the advertising data, such a definition makes the model inconsistent with the price data. Similarly, a definition of the introductory period that makes the model consistent with the price data causes it to be inconsistent with the advertising data. In short, there is no definition of introductory and post-introductory periods such that

[19]The sample attrition and business cycle explanation effects (more plausible for advertising since trends in advertising have not removed) were explored here as well, with similar negative results.

the predictions of the Nelson model and the data are consistent.

The HM, on the other hand, allows of a definition of the introductory period that makes the model consistent with both the advertising and price data over approximately the first three years. The model fails to pick-up the downturn in price and advertising for products that are well established in the sense of being on the market four years or more.

To some extent, this failure of the model is a result of the restriction to only two periods. To see why, consider an extension of the model to a third period. For the same reason that the two-period model failed to have a fully separating equilibrium, the three-period version will also fail to have one. As a consequence, the same sort of advertising equilibrium behavior that occurs in the second-period of the two-period model can occur in equilibrium in both the second and third periods of the three-period version. That is, in the advertising equilibrium, the firm will set a high price and advertise with certainty when quality is high and will randomize between this outcome and one involving a low price and no advertising when quality is low. A consequence of this randomization behavior is that, when the product is low quality, advertising and price can rise together in the second period (due to the randomization yielding the advertising outcome) and fall together in the third (due to the randomization yielding the other outcome). Thus in the three-period version, it is possible to observe price and advertising rising and then falling, as observed in the data. The model continues to predict that, when product quality is high, price and advertising will be (weakly) increasing with time.

The extent to which this generalization reconciles the model and data is as follows. With

heterogeneity in quality, some firms will have price/advertising paths that rise over time and others that are first rising then falling. The price and advertising paths predicted by the regression results above will be an aggregate of these paths and so can feature a declining region. Further, were the model to be extended to include additional periods, the equilibrium would be expected to yield firms with low quality all setting a low price and not advertising (the randomization ultimately must yield this outcome). The result will be an average price below the introductory price and average advertising levels below those in the second period. Essentially this outcome is what is in the data.

Finally, when advertising is measured relative to the average of the firm's observed advertising, the advertising series is much "noisier" and the regression results less statistically significant. The estimated advertising-experience profile is initially rising, then falling, but estimated with much less precision. The point estimates (the coefficients of $EXPER$ and $EXPER^2$ are .023 and -.0136.) imply that the increasing portion is roughly a year, rather than the two years found earlier; however, this estimate is very imprecise. Taken at face value, the tendency of advertising and price to move together remains, but advertising tends to turn downward before price. This advertising profile, given the previously-estimated price profile, is difficult to interpret using any of the signaling models discussed above. Whether this result is an anomaly in the context of signaling models, or simply an artifact of the imprecision in the advertising data, does not appear to be resolvable using these data.

5 Conclusion

This paper investigates whether signaling models of advertising are helpful for organizing the data on pricing and advertising of compact disc players. In the compact disc player data, price and advertising expenditure are initially rising and then declining with length of time a particular product has been on the market. Based on the most reliable measure of advertising, this outcome is inconsistent with the predictions of original signaling models of advertising, partially consistent with the HM signaling model, and consistent with a generalized version of a the HM model, lending support to the hypothesis that advertising serves as signal in an imperfect consumer learning environment.

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