

Marketing Information: A Competitive Analysis

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Abstract

Selling information that is later used in decision making constitutes an increasingly important business in modern economies (Jensen 1991). Information is sold under a large variety of forms: industry reports, consulting services, database access, and/or professional opinions given by medical, engineering, accounting/financial, and legal professionals, among others.

This paper is the first attempt in marketing to study competition in the rapidly emerging information sector. Specifically, we are interested in answering the following questions: (1) Is competition fundamentally different when competing firms sell information rather than traditional goods and services, and—if yes—why? (2) What are the implications of such differences for decision makers (marketers and regulators)? (3) Can we explain some of the observed marketing strategies in the information industry? As such, the audience of the paper includes academics as well as professionals who are interested in understanding what is specific about competition in information markets. Familiarity with the practical implications of such differences and understanding of the mechanisms that drive them is essential for those who are faced with the problem of marketing information.

To answer the above research questions we build a simple game-theoretic model that consists of two firms selling information to a population of consumers who are heterogeneous in their willingness to pay for the *quality* of information. The most important features of the model are the following. Information products sold by the two firms are modeled as random draws from two normal distributions having equal mean. The variances of these distributions and their correlatedness constitute the product-attribute space, which is assumed to be common knowledge. Consumers are interested in assessing the mean of the distributions and to do so they can buy the sample from any of the firms or they can buy both samples and combine them to obtain a more accurate estimate. *Quality* of information is linked to the accuracy of consumers' estimate of the mean which in turn is influenced by the accuracy of each sample as well as by their correlatedness. Consumers' utility depends on the quality of information they purchased,

on their inherent utility for quality (taste), and on the total price they paid to acquire information. Knowing consumer preferences, firms simultaneously price their information products.

The main finding of the paper is that information markets face unique competitive structures. In particular, the qualitative nature of competition changes depending on basic product characteristics. While traditional products and services compete either as substitutes or as complements in the relevant product-attribute space, information may be one or the other, depending on its position within the *same* product-attribute space. Said differently, the nature of competition changes *qualitatively* with a continuous change in basic product-attribute levels. The intuition behind this finding is the following. When purchasing information, consumers facing important decisions may find it beneficial to purchase from several information sellers. This is more likely to happen when the reliability of information is low and the sources of information are independent. Under such conditions information products tend to be complements and, as a result, competition between sellers is relatively mild. In the opposite case, when information is reliable and/or sellers' sources are highly correlated, consumers are satisfied after consulting a single source. In this case, information products are substitutes and sellers tend to undercut one another's prices to induce consumers to choose their brand.

Understanding this discontinuity in competitive structures has important implications for decision makers as very different strategies are optimal under different product characteristics. Under substitution, traditional strategies to avoid competition (e.g., differentiation) are recommended. When the competing products' reliability is generally low (they are complements) firms are better off accommodating competition. In fact, we find that a firm may benefit from "inviting" a competitor. Finally, our findings are also important for regulators of information markets. As the literature on complementarity suggests, price fixing agreements between firms offering complementary products may benefit firms as well as consumers. (*Information Sales; Competitive Strategy; Complements; Substitutes*)

Table 1 The U.S. Market for Information Services in 1988

Information Subject Area	Estimated 1988 Revenue (\$ billion)	Estimated 1988 Share (%)	Average Annual Increase in Revenue From 1982–1988 (%)
Market/Marketing/Media Research	6.6	37.3	13
Economic/Financial/Securities	3.9	22	16
Credit/Check Authorization	2.4	13.6	11
Product/Price	1.5	8.5	9
Legal/Regulatory	1.4	7.9	10
Medical/Scientific/Technological	0.8	4.5	12
All Others	1.1	6.2	8
Total Industry	17.7	100	12

Note: Adopted from Jensen (1991).

“... [the new statistical system designed for the Information Age] ... would consist of three economic sectors: goods-producing, services and information.”

“The Spawning of a Third Sector: Information,” *Business Week*, Nov. 7, 1994, p. 48.

1. Introduction

Recently, Portugal Telecom has simultaneously hired three independent investment banks to value the firm before its privatization. There are two decision problems underlying this story. From the Telecom’s point of view the question is: how many information sources to consult in order to obtain a fair estimate for the value of the firm? On the other hand, the investment banks’ problem is: how to price the consulting service given the uncertainty of the Telecom’s value and given the presence of competing investment banks providing valuation services? In essence, what is being exchanged in this example is *information*—in this specific case, information about the value of a firm. This paper seeks to explore similar situations faced by marketing managers who sell information products or services in a competitive setting.

Information products can take on a variety of forms: industry reports, consulting services, database access, and professional opinions given by medical, engineering, accounting/financial, and legal professionals, among others. The term “information product” is used

in a broader sense in the literature, including information technology, advertising, or the media. In contrast, our definition follows Jensen (1991, p. 424), by referring to *information that is (1) paid for, and (2) valuable for making decisions* (e.g., expert advice). Our discussion, therefore, excludes advertising since it is not paid for. Likewise, information which is used to entertain (e.g., movies) is also not explored. Jensen (1991) reports detailed statistics on the business-to-business sector of the information industry in the U.S.A. for the period 1982–1988. Table 1 shows that this \$17.7 billion industry is especially relevant for marketing where most of the revenues are generated.¹

Despite the dynamic development of the “information sector” (12% average annual growth over the 1980s) there is relatively little academic work devoted to the subject. The objective of this paper is to fill this gap by developing a simple game-theoretic framework to understand competition in information markets. In particular, we are interested in answering the following questions: (1) Is competition fundamentally different when competing firms sell information rather than

¹ In 1988 the U.S. information services industry included some 1,500—mostly small—companies. Examples of large information services providers include Dun & Bradstreet Business Information Reports, F. W. Dodge Construction Project News, IMS International Sales Territory Reports, and Consumer Reports among others.

traditional goods and services, and—if yes—why? (2) What are the implications of such differences for decision makers (marketers and regulators)? (3) Can we explain some of the observed marketing strategies in information markets?

The next section provides an intuitive description of the problem and relates our approach to the relevant literature. The model is formally developed in §3. In this section, care is taken to relate the analytic findings to observed business strategies. Before concluding, §4 briefly discusses potential limitations. To improve readability, details of the derivations as well as some extensions are reported in an appendix that is available from the authors upon request.

2. The Problem

2.1. Intuition

Traditionally, when we talk about “competing” products (brands) we think of differentiated substitutes. Most consumers choose one coffee brand over another or one car from a set of alternatives. When purchasing information, consumers facing important decisions may find it beneficial to buy from several information sellers. This is more likely to happen when the reliability of information is low and the sources of information are independent. Under such conditions, information sellers anticipate the consumers’ problem and tend to charge higher prices. In the opposite case, when information is reliable and/or sellers’ sources are highly correlated, consumers are satisfied after consulting a single source. In this case, sellers tend to decrease prices to induce consumers to choose their brand. In other words, higher correlation between information sources makes information products substitutes. Uncertainty and independence among information sources, however, make them complements.² What makes information different from other goods and services is that the latter

² In this paper we define substitutability and complementarity from the firms’ point of view by referring to the sign of the cross-price elasticity of demand. If it is positive, products are substitutes; in the opposite case they are complements. Had we taken the consumer’s viewpoint our conclusions would not differ from those of standard sampling theory with fixed sampling cost. The innovation in our model is that the “cost of sampling” is *endogenous*.

are either substitutes or complements in the relevant product-attribute space, whereas information may be one or the other depending on its position within the *same* product-attribute space. Said differently, the nature of competition changes *qualitatively* with a (continuous) change in basic product-attribute levels.³

To better illustrate this difference consider the following example.⁴ Imagine consumers of brass—a metal composed of zinc and copper—who are served by two brass sellers. Irrespective of product characteristics (qualities), their products will always be substitutes because one seller—at least partially—replaces the other. Firms are interested in decreasing prices to capture a larger part of the total demand. With identical firms one will observe marginal cost pricing. Consider now the case of two firms producing copper and zinc, respectively, for the same consumers. This time, irrespective of their characteristics (qualities), the two products are perfect complements. Purchasing from only one firm is pointless without purchasing from the other. In such a setting, firms do not try to undercut the competitor’s price but rather try to increase prices to extract as much surplus as possible from the total price that consumers are willing to pay for the *composite good*. The prices set by a monopolist producing both components is lower than the equilibrium prices under competition, and the monopolist largely makes up for the lost margins through a substantial increase in volume.

In competition, traditional goods behave either like brass (they are substitutes) or like copper and zinc (they are complements). What is interesting with information products is that—unlike most other goods—they are substitutes or complements depending on the levels of basic product characteristics, attributes which are in-

³ Technically speaking, for traditional goods the value of the cross-price elasticity may change with a change of basic product attributes but its sign does not. In the case of information products, changing the products’ attributes can result in a change of the sign of the cross-price elasticity of demand.

⁴ This example has been inspired by the earliest study on perfect complements by Cournot (1838). Economides and Salop (1992) provide a formal description of this Cournot model and a discussion on complements. Other important papers on complementarity include Matutes and Regibeau (1988), Economides (1989), and Gilbert and Riordan (1995).

herent to information: reliability (variance) and similarity (correlation). As a result, competitive behavior is very different in different regions of the product-attribute space. When information products are reliable or highly correlated, products are substitutes and competition between information suppliers is intense. When product reliability is low products are complements and competition between sellers is relatively mild (if reliability is a measure of quality, this may also mean that profits are higher when competitors have lower quality products). These findings are consistent with the general theory on substitutes and complements (see the references in footnote 4). In particular, we get the standard result that collusion or merger of firms producing perfect complements raises profits as well as consumer welfare (Allen 1938).

2.2. Related Literature

Our work is related to three important streams of literature: normative decision theory, industrial organization, and information economics. The focus of normative decision theory is the problem of a decision maker who has to acquire information before making decision(s). The goal is to assess the value of information in order to trade it off against its cost. In this context, the "cost" of information is exogenous or it is under the control of the decision maker. In modern economies, however, the price of information is endogenously determined in competitive markets. In this paper we focus on the supply-side of information markets and allow competing information sellers to set the price of information. In this respect our work is closer in spirit to the second stream, the literature on oligopolistic competition. In particular, our model is related to the literature on complementarity (see references in footnote 4) and the literature on vertical differentiation (Mussa and Rosen 1978, Gabszewicz and Thisse 1979, Shaked and Sutton 1982, Moorthy 1988) which assumes that consumers differ in their willingness to pay for higher levels of product quality.

We depart from the third stream of literature, the information economics tradition, in a number of ways. Economic theory considers information to be a "public good," that is, a good available for free. The argument is either that information does not perish when used, and therefore it can be resold after "consumption," or

that it gets revealed in the actions of the information users, so there is no incentive to purchase information. We depart from this tradition by realizing that, in modern economies, legal constraints (e.g., copyright laws) prevent the resale of information. We also assume that information is not revealed in the actions of the information users, this being an issue only when consumers can observe a large number of simple transactions (e.g. stock markets).⁵ Second, we do not consider the effects of information asymmetry due to opportunistic behavior of the firms (e.g., signaling or screening). In our discussion, information asymmetry exists to the extent that sellers hold tradable information of value to consumers.

3. The Model

"No two men see the world alike." (Goethe)

To illustrate the model we will use the example of competing consulting companies (firms) selling reports on the status of an industry and its future prospects to their clients (the consumers) who buy these report(s) to use them when planning their business strategies. A good example of this scenario is EMCI Inc., a U.S.-based company specialized in selling reports on the mobile telecommunications industry. There are, of course, many other types of consulting services. Often consultants provide diagnosis for clients or recommendations on how to implement a given marketing strategy. For the sake of illustration, we have picked one type of consulting firm that nicely captures the essence of information selling. Later we show that a very similar formulation would apply to other types of consulting services that involve diagnoses or recommendations.⁶

Besides consulting, this illustration is also analogous to a variety of other situations such as the competition

⁵ Important papers on this problem include Grossman and Stiglitz (1980), Admati and Pfleiderer (1986, 1988, 1990) and Sunder (1992).

⁶ Our discussion excludes situations where the consultant is also contracted to implement the recommended strategy. We restrict our attention to cases where only information is delivered to the consumer. A recent paper by Wolinsky (1993) looks at competition in a market for services offered by informed experts who also *diagnose* how serious the consumer's problem is. His paper focuses on opportunistic behavior when the expert has an incentive to overstate the seriousness of the problem.

between cardiologists providing medical diagnosis (Parker 1995), lawyers giving legal advice, or stock brokers giving buy/sell recommendations. In some of the cases (e.g., industry reports) prices are set once the product exists. In other cases (e.g., diagnosis or recommendation) the report is commissioned to the seller. Both situations are captured by our model as long as the parties can commit to the agreed price (i.e., if a "contract" is enforceable).⁷

It is not rare in practice that a firm buys and compares several reports, each from different consultants, to get a better picture of the industry. The number of reports that the client buys depends on the perceived reliability of each report (e.g., its perceived quality), on their perceived similarity (e.g., their perceived substitutability) and their prices. Knowing these perceptions, consultants simultaneously set prices. In this setting, product perceptions are exogenous and fixed. In the appendix, we briefly discuss the case of a two-stage game where firms first choose their positions in the perceptual space and then set prices for their products.

3.1. The Players and the Product Space

3.1.1. Firms Assume a duopoly that consists of two consultants selling reports. They have similar cost structures and for simplicity we assume that the marginal, as well as fixed cost of producing a report are 0. In the appendix, we show that our key findings are unchanged if we relax this assumption. Finally, we also assume that entry in the industry is not possible.

Suppose further that the information content of consultant i 's report consists of a number, x_i , that can be thought of as the predicted dollar value of total business opportunities in the industry. We assume that x_i is a random draw from a normal distribution with mean m , the true value of business opportunities and variance σ_i^2 , which represents the inverse of the "reliability" of firm i 's report. Had we used another scenario, x_i and m would mean different things. In the case of EMCI Inc.,

for instance, m is the true demand for cellular services and x_i is a demand forecast. Alternatively, if the report would be about the implementation of a marketing strategy (say the recommended size of the salesforce), m would be the "best" implemented solution (the optimal size).⁸ The reports issued by different firms do not have to be independent, and we suppose that the x_i -s are correlated with correlation coefficient ρ .⁹ Thus, the product space can be described with a bivariate normal distribution with mean vector (m, m) and covariance matrix

$$\Xi = \begin{pmatrix} \sigma_1^2 & \sigma_1\sigma_2\rho \\ \sigma_2\sigma_1\rho & \sigma_2^2 \end{pmatrix},$$

where all parameters are exogenous. At the time of the purchase decision, the value of m is unknown to all players and the σ_i^2 -s and ρ are common knowledge.¹⁰ In marketing terms, the $(\sigma_1^2, \sigma_2^2, \rho)$ space should be thought of as the relevant attribute space for information products. There are several ways to interpret this space. For example, comparing two firms, the σ^2 -s may be associated with firms' reputations. In another scenario, say, if the same firm produces two reports on two countries/industries, then the σ^2 -s could be associated with the business uncertainty of the respective countries/industries. Similarly, ρ reflects consumers' assessment of the similarity between the firms (the extent to which firms use similar data sources or methodologies, represent similar "schools of thought", etc.).¹¹

3.1.2. Consumers Consumers can choose to buy the report of firm 1, the report of firm 2 or both reports. For simplicity we will refer to these three alternatives as product configurations, indexed 1, 2, and Σ for the com-

⁸ We would like to thank the Editor for this insight.

⁹ Positive correlation of expert opinion is supported by empirical evidence. It can result from the fact that experts share some information sources or that they have similar priors due to common education, for instance. Negative correlation is unlikely but theoretically possible.

¹⁰ Later, the value of m may be revealed but this is irrelevant for the firms' current purchase decision. As it will become clear later, 1 is a natural limit for σ_i^2 , above which no consumer would purchase product i alone. Thus we will assume that $\sigma_i^2 < 1$ ($i = 1, 2$).

¹¹ Most consumers would expect, for instance, that a homeopath's perspective is different from a traditional MD's but they may assume that two MDs have quite similar views.

⁷ Whether price is set before or after the production of the information product, the seller may enter in price-discrimination by offering a menu of price-quality options to consumers. We would like to thank the Area Editor for drawing our attention to this important topic left for future research. The present model becomes intractable assuming both price discrimination and competition.

posite good. If the consumer buys one report, say from firm i , her estimate for m will be x_i with variance σ_i^2 . Upon buying two reports the consumer weights their contents using Winkler's (1981) weights which provide least-squared error forecasts.¹² Thus her estimate of m will be the composite product, \bar{x} with variance Σ^2 , where

$$\bar{x} = \frac{x_1(\sigma_2^2 - \sigma_1\sigma_2\rho) + x_2(\sigma_1^2 - \sigma_1\sigma_2\rho)}{\sigma_1^2 + \sigma_2^2 - 2\sigma_1\sigma_2\rho}$$

and

$$\Sigma^2 = \frac{\sigma_1^2\sigma_2^2(1 - \rho^2)}{\sigma_1^2 + \sigma_2^2 - 2\sigma_1\sigma_2\rho}.$$

Adopting the framework of the vertical differentiation literature, we assume that consumers are heterogeneous in their willingness to pay for the "quality" of the reports. The advantage of this approach is that we do not need to have specific assumptions on the way consumers use the purchased information.¹³ We need to define, however, what we mean by the "quality" of information. We will define *quality* of the purchased product configuration as a linearly decreasing function of the product configuration's variance.¹⁴

$$s_i = 1 - \sigma_i^2 \quad \text{if only firm } i\text{'s report is bought,}$$

$$s_\Sigma = 1 - \Sigma^2 \quad \text{if both firms' reports are bought.}$$

Given the constraints on the σ^2 -s, quality is allowed to vary between 0 and 1. Following the literature on ver-

¹² The literature on expert resolution is divided on which weighting scheme should be used to combine overlapping expert opinion. In the appendix, we discuss the practical problems associated with the use of Winkler's (1981) weights and argue that for empirically plausible ranges of the parameters the weighting scheme does not alter the substantive findings of the paper.

¹³ Notice that firms do not know the details of a consumer's decision problem which may in fact be specific to each consumer. Firms only have an aggregate view of the market; i.e. they only perceive how consumers are distributed in their willingness to pay for the reliability of information (see also footnote 15 on this issue).

¹⁴ We could have defined quality as $s = 1/\sigma$, but this would have lead to huge values of s in the case of reliable reports. Another advantage of our definition is that, in this way, the parameter space is finite and allows graphical illustration of the results (see later the argument on the uniqueness of the equilibria, for instance).

tical differentiation (see Tirole 1990, Chapter 2, pp 96) with a higher θ meaning that the consumer values the quality of information more or, equivalently, that she is more sensitive to potential losses from an inaccurate prediction of m .¹⁵ Another interpretation of θ is that it is the inverse of the marginal rate of substitution between income and quality (Tirole 1990), i.e. wealthier consumers have a higher θ . We assume that θ is known to be distributed across consumers between 0 and 1 according to the cumulative density function \mathcal{F} . Thus, there is a continuum of consumers and without loss of generality we normalize their total number to 1. Finally, note that utility does not depend on the content of the reports. As mentioned before, consumers do not know this value before making the purchase decision, so their *ex ante* utility for information should not depend on it.

$$U = \begin{cases} \theta(1 - \Sigma^2) - p_1 - p_2 & \text{if both reports are bought,} \\ \theta(1 - \sigma_i^2) - p_i & \text{if only firm } i\text{'s report is bought,} \\ 0 & \text{otherwise.} \end{cases} \quad (1)$$

Here, θ is a positive taste parameter (see Tirole 1990, Chapter 2, pp 96) with a higher θ meaning that the consumer values the quality of information more or, equivalently, that she is more sensitive to potential losses from an inaccurate prediction of m .¹⁵ Another interpretation of θ is that it is the inverse of the marginal rate of substitution between income and quality (Tirole 1990), i.e. wealthier consumers have a higher θ . We assume that θ is known to be distributed across consumers between 0 and 1 according to the cumulative density function \mathcal{F} . Thus, there is a continuum of consumers and without loss of generality we normalize their total number to 1. Finally, note that utility does not depend on the content of the reports. As mentioned before, consumers do not know this value before making the purchase decision, so their *ex ante* utility for information should not depend on it.

3.2. Demand Schedules

If a single report is offered by a firm expression (1) becomes $U = \theta s - p = \theta(1 - \sigma^2) - p$. The demand consists of those consumers whose net surplus is higher than 0:

$$D(p) = \Pr(U > 0) = \Pr(\theta > p/s) = 1 - \mathcal{F}(p/s). \quad (2)$$

With more than one product the demand conditions are

¹⁵ For example, in EMCI's context a consumer may only be interested in the "range" of m (i.e. if it is "large" or "small") to perform a rough break-even analysis. As σ^2 is bounded, this consumer is not really interested in further improving the accuracy of the forecast and has therefore a small θ . Another consumer may try to fine-tune a marketing strategy and is very sensitive to forecast variance. Consequently it has a higher θ . Consumer heterogeneity (including consumer's *ex post* valuation for m) is entirely captured by the distribution of the θ parameter. We would like to thank the Editor for these examples.

defined by the relative values of the “quality per dollar,” (s/p), of the different product configurations. One can show (see Tirole, 1990, pp 97. for a formal proof) that in the above vertical differentiation model, if $s_2 > s_1$ and $s_2/p_2 \geq s_1/p_1$ then product 1 gets no demand, since all consumers who decide to purchase will end-up buying product 2. Said differently, product 2 dominates product 1. When $s_2/p_2 < s_1/p_1$, however, some consumers purchase the lower quality product. Thus, with more than one product the demand function is piece-wise continuous: there is a different demand function depending on the quality/price ratios of the products.

In our case, there are three alternative product configurations: buying the higher quality report, the lower quality report or both reports. In the last case the price is the sum of the prices of the individual reports and the quality is always higher than any of the individual report's. We need to analyze all possible situations (a total of five) defined by the relevant relations between the quality/price ratios of *each* product configuration. In what follows, we will analyze in detail only two situations, because only these two lead to a pure-strategy equilibrium. In Section 1 of the appendix we develop the demand for the remaining cases and show that under these, no equilibria exist.

First, we will look at a situation where each product configuration is bought by some consumers. Without loss of generality, suppose that $\sigma_1 > \sigma_2$, i.e. $s_\Sigma > s_2 > s_1$. For the proposed demand structure to exist the following condition has to hold:

$$\frac{s_\Sigma}{p_1 + p_2} < \frac{s_2}{p_2} < \frac{s_1}{p_1}, \quad (3)$$

in other words, no product configuration dominates others for all consumers. Given prices p_1 and p_2 , we have for the marginal consumer who is indifferent between purchasing both reports and the higher quality report alone: $\bar{\theta}s_\Sigma - p_1 - p_2 = \bar{\theta}s_2 - p_2$. Thus, $\bar{\theta} = p_1/(\sigma_2^2 - \Sigma^2)$. Similarly, for the consumer who is indifferent between buying the higher quality report and the lower quality one we have: $\bar{\theta} = (p_2 - p_1)/(\sigma_1^2 - \sigma_2^2)$. Finally, the consumer who is indifferent between buying the lower quality report and not buying at all has taste parameter $\underline{\theta} = p_1/(1 - \sigma_1^2)$. Thus, the demand for the three configurations respectively can be written as:

$$D_\Sigma = 1 - \mathcal{F}\left(\frac{p_1}{\sigma_2^2 - \Sigma^2}\right)$$

$$D_2 = \mathcal{F}\left(\frac{p_1}{\sigma_2^2 - \Sigma^2}\right) - \mathcal{F}\left(\frac{p_2 - p_1}{\sigma_1^2 - \sigma_2^2}\right)$$

$$D_1 = \mathcal{F}\left(\frac{p_2 - p_1}{\sigma_1^2 - \sigma_2^2}\right) - \mathcal{F}\left(\frac{p_1}{1 - \sigma_1^2}\right).$$

Therefore, under condition (3) the demand faced by the two firms is:

$$\begin{aligned} D_I &= D_\Sigma + D_1 = 1 - \mathcal{F}\left(\frac{p_1}{\sigma_2^2 - \Sigma^2}\right) \\ &\quad + \mathcal{F}\left(\frac{p_2 - p_1}{\sigma_1^2 - \sigma_2^2}\right) - \mathcal{F}\left(\frac{p_1}{1 - \sigma_1^2}\right) \\ D_{II} &= D_\Sigma + D_2 = 1 - \mathcal{F}\left(\frac{p_2 - p_1}{\sigma_1^2 - \sigma_2^2}\right). \end{aligned} \quad (4)$$

The subscripts *I* and *II* are used to denote firm 1 and 2 respectively, to differentiate from the individual product configurations' demand. It is easy to see that $\partial D_{II}/\partial p_1 \geq 0$ and $\partial D_I/\partial p_2 \geq 0$, i.e. *under this scenario—when (3) is true—the two products are substitutes.*

Next, consider the scenario when the product configuration including both reports dominates all other product configurations. We have:

$$\frac{s_\Sigma}{p_1 + p_2} \geq \frac{s_2}{p_2} \quad \text{and} \quad \frac{s_1}{p_1}. \quad (5)$$

Then all consumers who decide to purchase at all will buy both products. No consumer will buy from only one firm. Following the same arguments as above, by finding the consumer who is indifferent between buying both reports or nothing, the demand for each configuration is:

$$D_\Sigma = 1 - \mathcal{F}\left(\frac{p_1 + p_2}{1 - \Sigma^2}\right) \quad \text{and} \quad D_2 = D_1 = 0.$$

Therefore, under condition (5) the demand faced by the two firms is:

$$D_I = D_{II} = D_\Sigma = 1 - \mathcal{F}\left(\frac{p_1 + p_2}{1 - \Sigma^2}\right). \quad (6)$$

Note, that now $\partial D_\Sigma/\partial p_i \leq 0$ ($i = 1, 2$), i.e. *under this scenario—when (5) holds—the two products are complements.*

the three additional demand schedules are the following. (1) When $s_2/p_2 > s_{\Sigma}/(p_1 + p_2)$ and $s_2/p_2 \geq s_1/p_1$, the configuration that consists of product 1 alone is dominated. As a result the demand of firm 1 consists only of the joint product configuration: $D_I = 1 - \mathcal{F}(p_1/(s_{\Sigma} - s_2))$ and $D_{II} = 1 - \mathcal{F}(p_2/s_2)$. (2) When $s_1/p_1 > s_{\Sigma}/(p_1 + p_2) \geq s_2/p_2$, the configuration consisting of product 2 alone is dominated and therefore $D_I = 1 - \mathcal{F}(p_1/s_1)$ and $D_{II} = 1 - \mathcal{F}(p_2/(s_{\Sigma} - s_1))$. Finally, (3) when $s_1/p_1 > s_2/p_2$ and $s_{\Sigma} \leq p_1 + p_2$, no consumer purchases the joint-product configuration. Thus, $D_I = \mathcal{F}((p_2 - p_1)/(s_2 - s_1)) - \mathcal{F}(p_1/s_1)$ and $D_{II} = 1 - \mathcal{F}((p_2 - p_1)/(s_2 - s_1))$. The derivations of these demand schedules follow the above logic and they can be found in the appendix.

3.3. Solutions of the Game

In what follows, we will analyze two cases. First, to set a benchmark we explore the model with a monopolist. Next, we take the case of two competing consulting firms. We compare the monopoly outcome to the equilibria under competition. For the remaining discussion we will assume that \mathcal{F} is the c.d.f. of the uniform distribution between 0 and 1.¹⁶ We also assume that $\sigma_i^2 < 1 \forall i$.

3.3.1. Monopoly The monopolist sells a maximum of one report to each client. Given our assumption on \mathcal{F} , (2) becomes $D(p) = 1 - p/(1 - \sigma^2)$. The optimal price charged by the monopolist is $p^M = (1 - \sigma^2)/2$. Output is $q^M = \frac{1}{2}$ and the monopolist's profit is $\pi^M = (1 - \sigma^2)/4 = s/4$. Given p^M and the uniform distribution of θ , total consumer surplus is:

$$\mathcal{S}^M = \int_{1/2}^1 [\theta(1 - \sigma^2) - p^M]d\theta = (1 - \sigma^2)/8 = s/8.$$

3.3.2. Duopoly In what follows we will show that in a duopoly there are two types of pure-strategy equilibria: one in which products act as substitutes (Proposition 1) and another in which products are complements (Proposition 3). For the case of symmetric competitors we will show that there is only a mixed-strategy substitute equilibrium (Proposition 2). The

equilibria exist. We will analyze these conditions and relate them to some observed market outcomes. Finally, we compare each equilibrium to the monopoly case. We begin by exploring an equilibrium where all three alternatives are chosen by some consumers and argue that—as in this case, products act as substitutes—there will be “intense” competition among information sellers.

PROPOSITION 1 (Substitutes). Assume that $\sigma_2 < \sigma_1$, i.e. $s_2 > s_1$ and consider the following prices:

$$p_1^* = \frac{3\delta d \Delta}{4\delta(\Delta + d) + 3d\Delta}$$

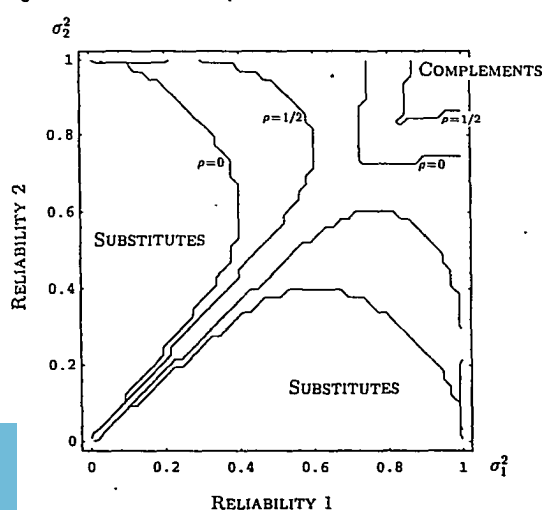
and

$$p_2^* = \frac{3\delta d \Delta + 2\delta^2(\Delta + d)}{4\delta(\Delta + d) + 3d\Delta}, \quad (7)$$

where $\delta = \sigma_1^2 - \sigma_2^2$, $d = 1 - \sigma_1^2$ and $\Delta = \sigma_2^2 - \Sigma^2$. Under conditions identified in the appendix and represented on Figure 1 these prices constitute a unique Nash equilibrium in pure strategies in which each product configuration is bought by some consumers and products compete as substitutes.

PROOF OF EXISTENCE (sketch). The logic of the proof is the following. First, we need to identify best response

Figure 1 Conditions for Equilibria



¹⁶ This assumption greatly simplifies the analysis by leading to linear demand functions. As long as \mathcal{F} is a unimodal distribution, the results are similar to the ones reported below.

pairs within a particular demand schedule. For example, in our case, we need to consider the demand schedule that is implied by condition (3), where no product configuration dominates any other for all consumers. Next, we need to verify if these pairs constitute a global equilibrium, i.e., if firms have no incentive to choose prices that change the demand schedule.

As shown before, under (3) firms face demand functions (4) and the products are substitutes. Using these demand functions, our assumption on \mathcal{F} , and supposing that firms choose prices in such a way that the demand schedule remains unchanged, we can compute the first-order conditions leading to the candidate equilibrium prices. These are equal to (7) (details are in the appendix). These prices need to fulfill condition (3) which results in the necessary condition for the existence of a substitute equilibrium: $d(3d + \delta)/(3d + 2\delta) > \Delta$ (see the appendix for an illustration and discussion of this condition).

Next, given the above necessary condition, we need to make sure that prices (7) constitute a global equilibrium. For that example, we know that as long as $p_2^*(s_\Sigma - s_2)/s_2 < p_1 < p_2^*s_1/s_2$ holds p_1^* is a best response to p_2^* , but what happens if firm 1 chooses a price outside this range? Similarly, we need to check under what conditions p_2^* remains a global best response to p_1^* . This tedious analysis, the result of which leads to the sufficient conditions for the existence of the equilibrium (Figure 1), is detailed in the appendix. \square

Figure 1 shows only two cross-sections of the parameter space, one at $\rho = 0$ and another at $\rho = \frac{1}{2}$. Other cross sections follow the same pattern. First, notice that products tend to compete as substitutes in the lower left half of the parameter space, i.e. when reliability (quality) is high. The figure also shows that the higher the correlation between the products the more likely they will compete as substitutes. Finally, when the products are undifferentiated (firms are symmetric) there is no pure strategy substitute equilibrium. This is because such an equilibrium would leave firms with 0 profits: prices (7) above become 0 when firms are symmetric ($\delta = 0$). Thus, it always pays to deviate and choose a price outside the range of the demand schedule implied by (3). Although there is not always a pure strategy equilibrium in the parameter region where we would expect

products to be substitutes there may be a mixed strategy equilibrium. The next proposition shows for symmetric competitors that in this region, there is a mixed strategy equilibrium that also results in tough competition between firms.

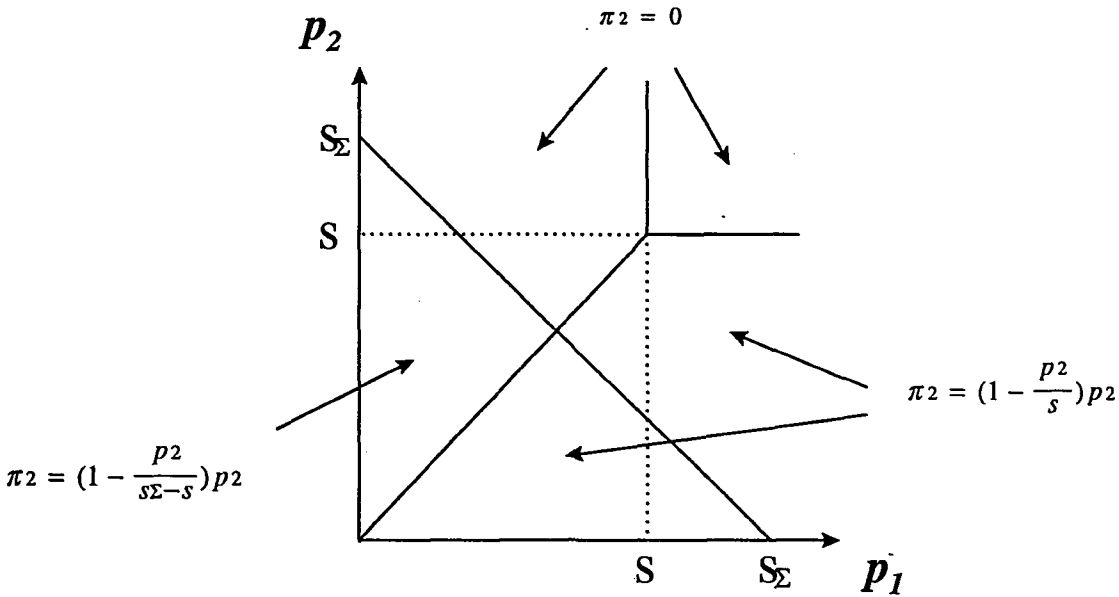
PROPOSITION 2. *Suppose that firms are symmetric ($\sigma_1 = \sigma_2$). If $2s > s_\Sigma$, i.e., $\rho > 3 - 2/\sigma^2$, then there is a mixed strategy equilibrium in which firms choose prices over the support $[(s_\Sigma - s)/2; s/2]$ with cumulative probability distribution*

$$F(p) = \begin{cases} \frac{s_\Sigma - s}{2s - s_\Sigma} \left(\frac{s - p}{p} - \frac{(s_\Sigma - s)(3s - s_\Sigma)}{4p^2} \right) & \text{if } (s_\Sigma - s)/2 \leq p < s/2 \\ 1 & \text{if } p = s/2. \end{cases}$$

In this equilibrium, profits are smaller than monopoly profits.

PROOF (sketch). Given the condition $2s > s_\Sigma$ consider the demand of firm 2 in the (p_1, p_2) space (see Figure 2 for an outline of the relevant cases). When $p_2 > p_1$ no consumer buys from firm 2 alone. When $p_1 + p_2 > s_\Sigma$, no consumer buys both reports. Finally, when both firms' prices are higher than s , there is no demand at all. Figure 2 shows the profit of firm 2 under these different scenarios. First, one can show that any price outside the $[(s_\Sigma - s)/2, s/2]$ interval is strictly dominated. Next, in a mixed strategy equilibrium, firm 2 has to be indifferent between any of the prices within this interval. This analysis yields the cumulative distribution over the prices in the proposition. To calculate the expected profit of the equilibrium, assume that firm 2 chooses price $(s_\Sigma - s)/2$. Then, it faces a demand $(1 - p_2/s) = (3s - s_\Sigma)/(2s)$ as all consumers buying a single report purchase from firm 2. Its profit, i.e. the equilibrium profit is $(3s - s_\Sigma)(s_\Sigma - s)/(4s)$ which is always less than the monopoly profit $s/4$. \square

What is the meaning of Propositions 1 and 2? The propositions identify the condition under which products clearly act as substitutes. Whether the equilibrium is in pure strategies (differentiated products) or mixed strategies (undifferentiated products) firms have an incentive to undercut each other's prices. The conditions say that for this to happen information products need



to be perceived reasonably reliable and/or correlated enough. In other words, in information markets with such product characteristics we can expect intense competition among sellers.

Now let us consider an equilibrium in which all consumers who decide to purchase at all buy both reports. We will argue that, in this equilibrium, products act as complements. Proposition 3 states the condition for such an equilibrium to exist.

PROPOSITION 3 (Complements). *Suppose that $\sigma_2 \leq \sigma_1$ (i.e. $s_2 \geq s_1$) and consider the prices:*

$$p_1^* = p_2^* = (1 - \Sigma^2)/3. \tag{8}$$

These prices constitute a unique, symmetric Nash equilibrium in pure strategies in which consumers buy zero or two reports if

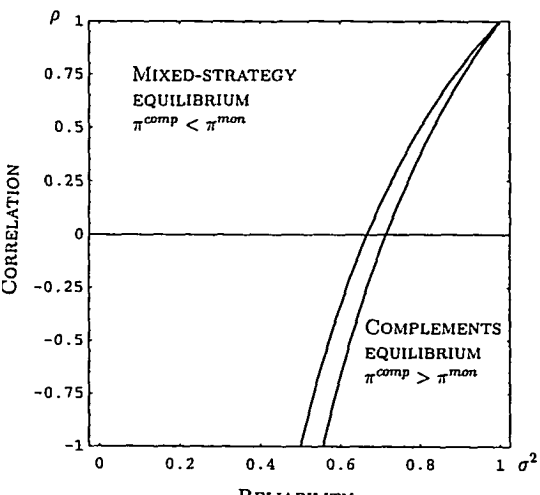
$$\rho \leq \frac{B - [B^2 - 4(B(\sigma_1^2 + \sigma_2^2) - 4\sigma_1^2\sigma_2^2)]^{1/2}}{4\sigma_1\sigma_2}, \tag{9}$$

where $B = 4 - 9(1 - \sigma_2^2)$. Under (9) competing products are complements.

PROOF OF EXISTENCE (sketch). Following the same logic as before, we first need to identify a candidate equilibrium within the demand schedule implied by condition (5). In other words, now the product configuration including both reports dominates all other product configurations. We have seen that in this case firms face demand functions (6) and the two products are complements. Using this demand, our assumption on \mathcal{F} , and supposing that firms do not choose prices that change the demand schedule prices (8) are best responses to each other. Note that these prices are symmetric even if the qualities of the reports are different, so the seller with the lower quality report “free rides” on the other. Feeding these prices back in condition (5) and taking into account that only the first inequality is binding we get the necessary condition $s_2 \geq 2s_1$ or $\Delta \geq d + \delta$, (see discussion in the appendix).

Again, this condition is only a necessary condition. Next, we need to make sure that the candidate equilibrium prices constitute a global equilibrium. This calculation is similar in spirit to the one in Proposition 1 and can be found in the appendix. It leads to the condition:

Figure 3 Conditions for Symmetric Competitors



$s_x \cong 9s_2/4$ which, after substitution, is equivalent to condition (9) of the proposition. \square

In this equilibrium, consumers perceive information as complementary. Anticipating this, firms price their reports in such a way that, in equilibrium, buying a single report makes no sense to anyone. In this case, each firm tries to extract as much surplus as possible from the total price that the consumers are willing to pay for the composite product, i.e. firms tend to increase their prices rather than undercut competition. This results in relatively mild competition. Complementarity also drives the free-riding effect in this equilibrium. If both products are bought by all consumers irrespective of qualities, there is no reason for consumers to pay a higher price for any of them.¹⁷ Proposition 3 says that for such an equilibrium to exist the reports have to be unreliable enough and not too correlated.

Summarizing, when the reports are reliable and/or highly correlated products compete as substitutes

¹⁷ The free-riding effect holds when firms are not too different. If perceived quality differences are very large then the firm with the higher quality may drive the other firm out of the market. Assuming the existence of marginal costs leads to different equilibrium prices but the free-riding effect persists in the sense that firms' profits are equal.

which results in intense competition between information sellers. This is true irrespective whether the products are differentiated (there is a pure strategy equilibrium) or undifferentiated (there is only a mixed strategy equilibrium). On the other hand, when the products are unreliable or highly correlated, products tend to compete as complements leading to mild competition between information sellers. To illustrate this finding we have plotted condition (9) on Figure 1. Also, Figure 3 shows the conditions of the different types of equilibria when $\sigma_1 = \sigma_2$. Observing these figures helps to understand the main message of the paper, namely that, unlike other goods, information products face very different competitive structures in different regions of the same product attribute space. This is best seen on Figure 3 i.e. when competitors are symmetric. Above the left curve there is only a mixed strategy equilibrium in which expected profits are smaller than the profit of a monopolist. Below the right curve there is an equilibrium in pure strategies where products compete as complements. In what follows, we will also see that in the latter case equilibrium profits are higher than the monopolist's (Proposition 4). It is this discontinuity in competitive structures that makes information products interesting.

How can we relate this finding to observed market outcomes? The model predicts that the more information products are correlated and the more reliable they are the more they become substitutes and the more competitors have an incentive to decrease prices. In the opposite case, products become complements and equilibrium prices tend to increase. This may explain the differences in competitive structures for different types of consulting services. Contrast valuation services (the case of Portugal Telecom) with market research for instance (IRI or AC Nielsen). Techniques for company valuation involve a fair amount of subjective assessment especially when intangible assets need to be taken into account. They also differ substantially in their approach. These methodologies are typically perceived to be unreliable—not because of a lack of expert competence but rather because of the nature of the problem. As a result, in most IPO-s (Initial Private Offerings), or take-overs, multiple consultants are hired to assess the value of the target firm. In contrast, market research techniques used by IRI or AC Nielsen tend to provide

similar and quite accurate results. It is rare that a firm would hire both companies simultaneously¹⁸ and, as a result, competition is fierce in this business. The model also helps us understand the contrast between competition of consultants in Eastern Europe and western countries. It is not rare to observe multiple consultations in East European countries where the economy is undergoing fundamental changes. Despite the fact that import costs are lower (firms hire locals) and consulting advice is less reliable due to the general lack of experience in economic environments under transformation, consultants are able to maintain fee structures comparable to western countries'. The reason is that in risky environments the combination of different opinions may lead to a better decision, i.e. information products are complements.

Based on these examples, one might naturally ask: are there conditions under which a monopolist is better off facing a competitor? We can address this question by comparing profits and consumer surplus under competition and monopoly. For symmetric competitors, we have already seen that, under substitution, competitive profits are lower than monopoly profits. When no consumer buys a single report (reports are complements) this is no longer the case. The following Proposition establishes that under the conditions of Proposition 3 a monopolist is better off encouraging the entry of a competitor.

PROPOSITION 4. *Suppose that the condition of Proposition 3 holds. Then profits and consumer surplus are higher under competition than under the monopoly regime of any of the two firms.*

PROOF. To prove this proposition we need to compute firms' profits and consumer welfare. In a complements equilibrium, the demand for the configuration that includes both products (that is the sales of both firms) is $D^C = \frac{1}{3}$, thus, firms' profits are $\pi^C = (1 - \Sigma^2)/9 = s_{\Sigma}/9$ and consumer surplus is:

$$\begin{aligned} S^C &= \int_{2/3}^1 \{\theta(1 - \Sigma^2) - \frac{2}{3}(1 - \Sigma^2)\}d\theta \\ &= (1 - \Sigma^2)/18 = s_{\Sigma}/18. \end{aligned}$$

When $s_{\Sigma} \cong 9s_2/4$, both profits and consumer welfare are higher in this equilibrium than under monopoly irrespective of which firm is the monopolist. \square

The intuition behind Proposition 4 is the following. When products are complements the quality and the price of the composite good alone determine the demand. When the individual reports' perceived reliability and correlation is very low, the increase in quality is very high after the combination of the reports. In other words, the base demand increases significantly. At the same time prices do not fall as shown in Proposition 3.

This finding may explain an apparently irrational behavior of EMCI Inc. (the publisher of industry reports, discussed earlier). EMCI seems to *encourage* the entry of competition by regularly swapping its client mailing lists with competitors.¹⁹ In this way the firm increases the chance that his client base will overlap with competitors'. Table 2 sheds some light on why such a strategy may make sense. It shows industry forecasts for cellular services by several well-known consultants. The data illustrate that forecasts in the cellular industry are very uncertain: forecasts (even by the same firm) show very high variance. While there may be a number of reasons for this to happen, a buyer relying on this data will assume that these information products are typically unreliable. Realizing that their products are complements, EMCI does not expect that clients will purchase from competitors *instead* of EMCI. It expects them to purchase from both.

Finally, we would like to explore, what happens if competitors collude when setting the price of information products? The discontinuity in competitive structures suggests very different outcomes. When products are substitutes, collusion leads to increased prices, higher profits and lower consumer welfare. When the products are complements, this is no longer the case. It is a classic result that under complementarity, collusion while increasing profits leads to lower prices and higher

¹⁸ According to a recent survey by Mercer Management Consulting, only about 17% of consumer packaged goods manufacturers simultaneously purchase information from both IRI and AC Nielsen. We would like to thank Alan Montgomery for this example.

¹⁹ Based on a personal interview with the company chairman, September 20, 1993.

Table 2 Cellular Subscriber Projections In the 1980s

Source	Date of Projection	Population Included	Date Projected for	Number of Subscribers (Millions)	
Yankee Group	1985	Total Market	1990	0.43	
Shosteck Associates	1983	Urban Pop.	Potential	0.53	
Shosteck Associates (a)	1987	n/a	1995	9-12	
A. D. Little	1980	Total Market	1990	1	
A. D. Little (b)	1985	n/a	1994	3	
Cellular Business Systems (c)	1985	n/a	1993	3.8	
BCG	1985	Total Likely	1990	1.2	
Link Resources	1984	Total Market	1990	1.4	
EMG	1985	Total Market	1990	1.8	
Business Comm. Co. (d)	1985	n/a	1993	1.3	
Lehman Brothers	1982	Top 90 Markets	1989	2	
Dean Witter	1982	Total Market	1990	2.1	
IRD	1980	Total Market	Cellular	2.5	
RRNA	1985	Total Market	1990	2.6	
Goldman Group (e)	1988	n/a	2000	9	
DLJ	1985	Top 90 Markets	1990	2.6	
Leigh	1982	Urban Pop.	1990	3	
Arthur Andersen	1984	Total Market	1990	7	
AT & T (f)	1985	n/a	2000	30-40	
			Actual Market	1990	5.2

Sources: Telocator, February 1986, pp. 22-27. (a) Telephone Engineer and Management, July, 1987. (b) Washington Business Journal, April 1, 1985. (c) Charlotte NC News, June 17, 1985. (d) New York Times, June 23, 1985. (e) Cellular Business, January, 1988. (f) Peoria Illinois Journal Star, May 26, 1985.

consumer surplus (Allen 1938). Thus, the analysis above suggests that when information is unreliable and the sellers' sources are independent, competition may not necessarily lead to the increase of social welfare. Said differently, mergers or price fixing agreements may be socially beneficial under these circumstances.²⁰

²⁰ The trade press has recently discussed a number of interesting cases related to the regulation of the information industry. Examples include the Federal Court's opposition to the merger of IRI and AC Nielsen (*Business Week*, Dec. 7, 1987), the successful acquisition of Arbitron's SAMI service by IRI from Control Data Corporation, (*Advertising Age*, Oct. 8, 1990, p. 82), the merger of Dialog and Data-Star (*Online*, July, 1993; *Information World Review*, March, 1993; *Information Today*, April, 1993), and that of two other information providers, Dow Jones News/Retrieval and Data Times (*Information Today*, Sept. 1990; *Link-Up*, May/April, 1992). See also recent discussions on the regulation of referral firms (e.g., Olson, 1989).

4. Model Limitations

The proposed model has made several simplifications. First, the present paper studies competition in a duopoly. Assuming more firms may be interesting because it is possible that competition of three firms providing complementary information may be socially more efficient than a duopoly (i.e. it pareto dominates a duopoly). In the present model this is not the case. More precisely, an equilibrium where each consumer buys from all three information sellers does not exist. The intuition behind this finding is that combining expert information has decreasing returns in terms of the accuracy of the final forecast, especially if expert opinions are correlated.²¹

²¹ In our model the quality of information is linearly decreasing in variance. It is possible that under a different specification a market

Second, our model uses a specific definition of information. In the appendix, we examine the case where information has a somewhat different meaning. In this extension, information suppliers have different information structures (in the sense that their partitions of the state space are different) and consumers are interested in having the finest possible partition of the state space (see Milgrom, 1981 for details). The informal analysis indicates that the results are similar to the ones found here.

Finally, our model considers a simultaneous one-shot game. This is justified in many situations. It is not uncommon that managers need to make one-shot decisions to buy from one, two or no information sources due to the lead time required to collect the data and the lack of time post delivery to order additional opinions before decision making. In reality, the purchased information is rarely a simple value as modeled here. Thus, the evaluation of the reports may be lengthy, and consumers have to gather information before full evaluation is possible.²² Often, purchasing information means subscription to an on-line database. This decision may be independent from a specific application of the database.

From a modeling point of view we have chosen a static game for two reasons: First, our utility function depends only on the reliability and dependence of the reports and this is assumed to be common knowledge. A dynamic model, therefore, would provide the same results. One could consider the case where the utility for additional information depends on the value of previously purchased information (i.e. the purchase of the second report is contingent on the content of the first). In this case firms would make their prices

with more than two competitors can dominate a duopoly. Even in this case the size of the market would be limited to a few competitors due to decreasing returns to combining information. In reality, we would expect consumers to consider only a subset of potential information providers, those that are minimally correlated. However, we do not explicitly model such sequential search by consumers and this is clearly a limitation of the paper.

²² When evaluating marketing effectiveness using scanner data, for example, clients of market research companies, such as AC Nielsen or IRI, have to order all marketing research well in advance, before seeing the result(s) of any reports.

contingent on the value of their own reports. This would allow rational consumers to extract the information in the reports from the observed prices without buying the reports, i.e. the market would break down. Our model preserves the rationality of consumers and the existence of the market by assuming a simultaneous game.

Another way to think of a dynamic model is to assume an endogenous perceptual space. This has been partially done in the appendix, where we consider a two-stage game where firms first choose their positions in the perceptual space at some fixed cost and then compete in price according to the present model. This setting assumes that firms can easily communicate their product's quality to consumers (i.e. they can easily change consumers' quality perceptions). It could be interesting to model how consumers learn about firms' qualities in a context where communicating quality is only possible through repeated confrontation of the report with the "truth" revealed *ex post*. Finally, the explicit consideration of entry and exit may also lead to interesting insights. Addressing these questions through dynamic models of information markets is a challenging task left for future research.

5. Concluding Remarks

This paper proposes a game-theoretic model to explain competitive structures in markets for information. Such markets become more and more common with the development of information technology and the services industry. Our approach concentrates on modeling competition, given the interdependencies among information products.

Our investigation suggests that these externalities lead to counter-intuitive results regarding competitive structures that require radically different managerial actions. Specifically, we find that the qualitative nature of competition changes with the variation of the basic product-attribute levels (reliability and correlation). When information products are reliable or correlated they tend to compete as substitutes which results in fierce competition between firms. On the other hand, when information products are unreliable and uncorrelated products tend to be complements leading to relatively mild competition. Some examples in the

information services, medical and legal professions are provided to illustrate these conclusions.

It is important for managers to understand this feature of information markets as such radical differences in the nature of competition suggest very different strategies. Under substitution, traditional strategies to avoid competition (e.g., differentiation) are recommended. In contrast, we have seen that when the products' reliability is generally low (they are complements), firms are better off accommodating competition. In fact, under certain conditions a firm may benefit from "inviting" a competitor. Finally, our findings are also important for regulators of the information market. As the literature on complementarity suggests collusion between firms offering complementary products may benefit firms as well as consumers.

Information is often only one aspect of the total product/service sold which suggests that the results reported here may have wider applicability than "information-only" products. It is important to realize that in these cases our results can not explain *alone* the observed market outcomes but only provide insight with respect to information-related aspects. In the previous section, we have also highlighted a number of interesting—mostly theoretical—research directions. Beyond theoretical development there is potential for empirical research to test the proposed theory.²³

²³ The authors would like to thank Rajiv Lal, Patrick Rey and Rafael Rob for their helpful comments on earlier drafts. We are extremely grateful to the Editor, the Area Editor and the two anonymous referees for their suggestions on the manuscript. All errors are ours.

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