Operations Research Letters 46 (2018) 418–423

Contents lists available at ScienceDirect

Operations Research Letters

journal homepage: www.elsevier.com/locate/orl

Costly information acquisition under horizontal competition

Qi Fu, Yongquan Li, Kaijie Zhu *

Faculty of Business Administration, University of Macau, Taipa, Macau,
Economics and Management School, Wuhan University, Wuhan, China
Faculty of Business Administration, Chinese University of Hong Kong, Shatin, Hong Kong

ARTICLE INFO

Article history:
Received 15 June 2017
Received in revised form 15 May 2018
Accepted 15 May 2018
Available online 22 May 2018

Keywords:
Information acquisition
Horizontal competition
Game theory

ABSTRACT

We analyze endogenous acquisition of costly information for two firms that sell homogeneous products. Prior to determining its production quantity, either firm has an opportunity to acquire a costly forecast. There exists a correlation between errors in the acquired forecasts. We model the problem as a two-stage game in which the firms first decide whether to acquire their respective forecasts and then decide their production quantities. We derive the equilibrium outcome on information acquisition and production quantity.

1. Introduction

Globalization of the economy, advances in technologies, and changes in consumer tastes have intensified the competition in nearly all the industries, which in turn creates tremendous challenges and difficulties for firms. To survive and excel in such intensified competition, firms need to rely heavily on acquiring and using information for making better decisions. In particular, recent developments in big data analytics provide numerous opportunities for firms to collect and analyze business data from various sources, including e-commerce platforms, social networks, and search engines, and extract useful information from the data. According to [1], 46% of the companies surveyed report that big data analytics helps them understand their market better and hence achieve improvements in demand fulfillment and customer service of 10% or more.

In reality, it is often the case that significant efforts and costs have to be put into acquiring information. For instance, when companies want to conduct market surveys to gain a better understanding of customer demand, they need to set aside budgets and organize personnel accordingly. Even with the increasing availability of data from various sources, turning the data into useful and reliable information requires much expertise in statistical analysis and data mining, which is not readily available unless up-to-date software and hardware are purchased and professionals of related disciplines are hired or consulted with, not mentioning costs spent on training managers and staffs in learning and understanding analytics results. As a matter of fact, according to [1], despite the acknowledged benefits big data analytics can generate, the biggest obstacle to its adoption is the large investment required to deploy and use analytics (67%). Therefore, in deciding on whether to acquire information or not, a firm should take into account the tradeoff between the cost of information acquisition and the value of acquired information.

In the presence of horizontal competition, measuring the exact value of acquired information becomes a challenging task for a firm. In fact, when its competitors acquire information as well, correlation may exist between the information acquired by the firm under consideration and that by the competitors. This can be the case in reality when information acquired by different parties shares a common set of business data, utilizes similar data mining/learning techniques, or even comes from the same agent or source. In such a situation, further decisions based on acquired information (such as production quantities) can be rather complicated. On one hand, a firm needs to make its decision based on the sample outcome of the acquired information. On the other hand, due to the information correlation, the firm somehow expects the information acquired by its competitors and hence needs to adapt its decision making to their decisions. Therefore, quantifying the value of acquired information to the firm should take into account strategic responses by its competitors.

In this paper, we develop a game-theoretic framework to model and analyze endogenous acquisition of costly information in the presence of horizontal competition. More specifically, we consider a stylized model in which two firms sell homogeneous products to the same market with random demand during a single season. Prior to determining its production quantity, each firm has an option to buy some information from some source, e.g., consultants

* Correspondence to: Faculty of Business Administration, Chinese University of Hong Kong, Shatin, Hong Kong.
E-mail addresses: gracefu@umac.mo (Q. Fu), yq.li@whu.edu.cn (Y. Li), kzhu@baf.msmail.cuhk.edu.hk (K. Zhu).

https://doi.org/10.1016/j.orl.2018.05.003
0167-6377/

who are capable of collecting market information and/or developing theoretical/computer-based models. For ease of presentation, we call the purchased information a forecast. The forecast can give the firm a better knowledge of the demand and hence facilitates its decision making. For example, if the forecast indicates a disappointing market, the firm can choose to produce less. We model the problem as a two-stage game in which the two firms first decide on whether or not to acquire their respective forecasts in the first stage and then decide on their respective production quantities.

Our analysis reveals that the value of information gained by a firm depends on both its own and the other firm's information acquisition decisions. Specifically, if only one of the two firms moves unilaterally to information acquisition while the other chooses to stay with no information acquisition, the former will gain a positive value of information while the latter's expected profit keeps unchanged. If the latter also chooses to acquire information, it will gain a value of information as well, but that gained by the former will decrease. The value of information gained by a firm is then compared with the cost of information acquisition, which in turn yields the equilibrium outcome of the game under consideration.

One interesting result from our analysis is that in equilibrium, given all else the same, it is possible that a firm having a higher information acquisition cost (not the other with a lower acquisition cost) will purchase forecast information. We also find that a high degree of correlation between forecast errors will discourage the firms from purchasing the forecasts simultaneously, which implies that only highly differentiated forecasts are fully marketable and that information sellers should seek different sources to ensure the differentiation.

The remainder of the paper is organized as follows. In Section 2, we review the relevant literature. In Section 3, we state the model and assumptions. We present discussions in Section 4. All the proofs are provided in the appendix.

2. Literature review

Our paper is closely related to the literature on acquisition of costly information. In the seminal work of Milgrom and Robert [13], the authors consider a seller that can survey a fraction of its customers to learn their exact demand before production and demonstrate the substitution effect between information and inventory. Zhu and Thonemann [18] generalize the model to the case of correlated customer demands and allow imperfect information. Uckun et al. [17] consider a supply chain in which a retailer orders from a supplier to meet warehouse demands where technology investment can be made to eliminate inaccuracy faced by each warehouse. They examine both centralized and decentralized systems with and without inventory pooling. Li and Zhu [10] compare static and sequential approaches to costly demand information acquisition decisions for a new product introduction problem and show that the latter can generate significantly higher profits under certain environments. Fu and Zhu [4] investigate the optimal information acquisition level in a supply chain setting and discuss channel coordination under various supply contracts. While we also study costly information acquisition, we differ from this stream of literature by taking into account horizontal competition and offer rather different results from those presented in the literature.

Another stream of related literature is information sharing in supply chain management. Early works in this stream focus on the benefits of information sharing in improving supply chain performance. Readers may refer to Chen [3] for an excellent review of the early literature. Here we review more recent studies. Li and Zhang [9] study the impact of confidentiality on incentives for sharing information vertically in a supply chain. Ha and Tong [5] investigate vertical demand information sharing in two competing supply chains and show information sharing benefits a supply chain under quantity-based contracts, while it is no longer the case under linear price contracts. Ha et al. [6] examine how the value of vertical information sharing is affected by signal accuracy, production diseconomy, and the type of competition. Özer et al. [15] discuss the role of trust in information sharing. Li et al. [12] take uncertainty in information acquisition into consideration, and discuss sharing information status instead of information content. Shang et al. [16] consider information sharing between a common retailer and two competing manufacturers and study the firms' information contracting and pricing decisions. It is worthwhile mentioning that some other works examine the impact of information leakage in various supply chain settings [2,7,8,11,14]. In our research, a firm may acquire forecast information, but the firm has no incentive to share/leak the information with/to another one.

3. Model and assumptions

We consider two firms, indexed 1 and 2, that sell a homogeneous product to the same market. The two firms engage in a Cournot competition. Each firm i, $i = 1, 2$, decides its production quantity q_i. Thus, $q_1 + q_2$ is the total quantity of the products available in the market. The selling price of the products, p, is determined by a linear inverse demand function of the total quantity, $q_1 + q_2$, as $p = a - q_1 - q_2$, where the intercept a is uncertain, representing the market potential.

The prior knowledge on the market potential is a distribution and we assume that such distribution information is common knowledge to both firms. Prior to determining its quantity decision, firm i has an option to acquire a forecast, which we denote by z_i. Acquiring the forecast is not free, and the firm needs to pay an information acquisition cost of k_i. That is, either firm may choose to exert effort to improve its knowledge on the market potential a.

To model the knowledge on a, we employ a Bayesian framework. In particular, we assume that prior distribution for a is normally distributed with mean μ and variance σ^2, i.e., $a \sim \mathcal{N}\left[\mu, \sigma^2\right]$. On the other hand, the forecast error of z_i, $z_i - a$, is normally distributed with zero mean and variance τ_i^2, i.e., $(z_i - a) \sim \mathcal{N}\left[0, \tau_i^2\right]$. Note that the mean of forecast error being zero indicates that the forecast is unbiased. We assume that $z_i - a$ and a are independent. However, when both firms acquire their respective forecasts, the forecast errors, $z_1 - a$ and $z_2 - a$, are correlated with coefficient ρ, where $\rho \in [0, 1]$. This assumption implies that there can be some dependence between the information delivered by the two forecasts (due to utilizing similar forecasting techniques, sharing common industrial data, or even coming from the same source).

It is straightforward that acquiring and utilizing the forecast z_i allows firm i to improve its knowledge on the market potential a. For notational conciseness, we define t_i as the ratio between the variance of a and that of z_i, that is, $t_i = \frac{var[a]}{var[z_i]} = \frac{\sigma^2}{\tau_i^2+\sigma^2}$. Note $t_i \in (0, 1)$, which can be viewed as a measure of the forecast quality. Specifically, for given σ^2, the larger the value of t_i, the smaller the value of τ_i^2, and thus the higher the quality of the forecast. Then, we can obtain the posterior distribution of a given z_i as follows:

$$a|z_i \sim \mathcal{N}\left[(1 - t_i)\,\mu + t_i z_i,\, (1 - t_i)\,\sigma^2\right]. \tag{1}$$

As is clear, the posterior mean of $a|z_i$ is a weighted average of the prior mean μ and the forecast z_i, where the weight on the forecast is t_i. Besides, the posterior variance is decreasing in t_i. These facts mirror the intuition that increasing the forecast quality associated with z_i (or equivalently, increasing t_i) improves firm i's knowledge on the market potential a.

We let ϕ and Φ be the probability density function (pdf) and cumulative density function (cdf) of a standard normal distribution, respectively. For notional conciseness of the analysis below, we introduce the $r = \frac{\sigma^2+\rho\tau_1\tau_2}{\sigma^2}$. Managerially, we can show r is the