ARTICLE IN PRESS

International Journal of Production Economics xxx (2017) 1–10

Contents lists available at ScienceDirect

International Journal of Production Economics

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

Possible market entry of a firm with an additive manufacturing technology☆

Richard F. Hartl[a,*], Peter M. Kort[b,c]

[a] Dept. of Business Administration, University of Vienna, Oskar Morgenstern Platz 1, 1090, Vienna, Austria
[b] Dept. of Econometrics & Operations Research, CentER, Tilburg University, The Netherlands
[c] Dept. of Economics, University of Antwerp, Belgium

ARTICLE INFO

Keywords:
Market entry game
Entry deterrence
Entry accommodation
Hotelling line
Additive manufacturing

ABSTRACT

One of the principle characteristics of additive manufacturing is that customers get access to their own design, i.e., they need not choose from a small number of standard products. The paper considers a framework where an incumbent with a standard technology produces a limited number of standard products, and faces a potential entrant with an additive manufacturing technology. We find that three different outcomes are possible: the incumbent accommodates entry while producing just one product, blockades/deters entry, or it has to leave the market due to too heavy competition from the entrant. We give conditions under which each of these outcomes will occur.

1. Introduction

A prime example of additive manufacturing (AM) is 3d printing, where a three-dimensional object is 'printed' (built) by adding layer after layer of a particular material (Rayna and Striukova (2014)). Although the technology is rather new, a variety of papers has been written on AM. Different aspects of AM have been considered in the literature, e.g. the property that manufacturers can shorten the length of the supply chain, or can build complex parts more easily whose production with conventional methods would be difficult or impossible (see, e.g., Achillas et al. (2015) or Ashourpour et al. (2016)). Other papers focus on the design for AM (Gao et al. (2015)). Several contributions have emphasized the increased flexibility compared with conventional methods (see, e.g., the review by Huang et al. (2012)). Additive Manufacturing has also been identified as "transforming operations and strategy" (see, e.g., D'Aveni (2015) and Eyers et al. (2016)).

Additive manufacturing production technologies design products exactly the way consumers want. This falls into the category of mass customization where companies enable customers to get access to a product that is exactly constructed according to their wishes. Products are produced one by one, so that they are not subject to economies of scale.

Rayna and Striukova (2014) argue that, just like the digitization of other products (music, movies, books), 3d printing is going to be very disruptive, as it enables digitization of objects. As such, the technology of 3d printing promises to considerably influence the economy (Mc Kinsey Global Institute (Disruptive technologies: Advances that will transform life, business, and the global economy)). Technological progress causes that costs continue to fall and capabilities of 3d printers increase (McKinsey Quarterly (January 2014)). The same article argues that consumers are willing to pay a premium for a bespoke design. This was confirmed by Franke et al. (2010), who found empirical evidence for the "I designed it myself" effect creating significantly higher willingness to pay. Such benefits make that 3d printing is going to threaten the position of established firms and create opportunities for newcomers, which facilitates market entry for new players.

Choi and Sethi (2010) state that the literature reported very little analytical results an economic models for mass customization supply chains. This statement is still true, and the aim of this paper is to fill this gap. To do so we propose an economic model which is as simple as possible, while at the same time capturing the most important properties of AM.

We set up a heterogenous product market and compare the performance of a standard and an additive manufacturing technology. We consider a game with an incumbent that uses a standard production technology, and a potential entrant that has access to an additive manufacturing technology. We employ the classic Hotelling (1929) model to describe the heterogenous product market. In this model different consumers are located on a line at different places. Another interpretation of the model, which is in fact the one we use, is that consumers have heterogenous tastes, where, for instance, the degree of sweetness corresponds to a location on the line.

☆ The authors are indebted to the participants of the 19th International Working Seminar on Production Economics for valuable discussions.
* Corresponding author.
E-mail addresses: richard.hartl@univie.ac.at (R.F. Hartl), kort@tilburguniversity.edu (P.M. Kort).

http://dx.doi.org/10.1016/j.ijpe.2017.06.013
Received 29 April 2016; Received in revised form 7 June 2017; Accepted 8 June 2017
Available online xxxx

The Hotelling model is a perfect instrument to illustrate the main difference between a standard and an additive manufacturing technology. The standard technology delivers goods, the taste of which corresponds to particular places on the Hotelling line. Most consumers' locations will not correspond to the location of such a good, and purchasing such a good implies that the consumer needs to pay transportation costs (in the taste interpretation, they incur a utility loss from not consuming their preferred product). As stated above, the additive manufacturing technology however, designs products exactly the way the consumers want. This implies that on the Hotelling line the consumer and product location exactly match so that no utility loss needs to be incurred of not consuming the perfect product.

We find that three different outcomes are possible:

- The incumbent accommodates entry.
- The incumbent blockades or deters entry.
- The incumbent leaves the market due to too heavy competition from the entrant.

We give conditions under which each of these outcomes will occur. For high levels of horizontal differentiation, competition forces the incumbent to exit. In situations where horizontal differentiation is limited, set up costs of the incumbent are low, and high entry costs, the incumbent applies an entry deterrence policy by introducing a large enough variety of products to make entry unprofitable. Otherwise the incumbent accommodates entry where the incumbent offers just one product in the case of large consumer utility.

The paper is organized as follows. Section 2 introduces the incumbent model with the standardized technology. The entrant with the additive manufacturing technology is introduced in Section 3 and the incumbent-entrant game is analyzed. Section 4 concludes.

2. Incumbent with standard technology

"Starting point is the traditional Hotelling (1929) model of spatial competition, which is derived from Lerner and Singer (1937). The spatial competition models using the Hotelling framework are extremely well known in the industrial organization literature. Consumers are uniformly distributed along a line on which firms are located that sell products. D'Aspremont et al. (1979) consider a duopoly, assume transportation costs to be quadratic, and show that there is a tendency for both firms to maximize their differentiation. Brander and Eaton (1984) consider sequential decisions by multiproduct firms leading to equilibria in which a single firm monopolizes close substitutes. A setting with two incumbents and an entrant is studied by Donnenfeld and Weber (1992). They derive that the threat of later entry relaxes the degree of product competition. Aguirre et al. (1998) explore the strategic properties of pricing rules and find that spatial price discrimination may be used for entry deterrence purposes. Kats (1995) considers a circle rather than a line, assumes linear transportation costs, and obtains that this model has a subgame perfect equilibrium in pure strategies. An empirical application of the Hotelling framework with respect to the ready-to-eat breakfast cereal industry is provided by Schmalensee (1978).

This paper extends the literature on Hotelling models by introducing an additive manufacturing technology. Additive manufacturing technologies are able to make tailor-made products. In terms of the Hotelling model this means that no disutility due to transportation costs occur. Below we start out describing the problem of the incumbent using a standard technology. Additive manufacturing is introduced in Section 3.

In this variant the economy that is envisioned consists of one industry. Ignoring the entry threat by a firm using additive manufacturing for the moment, we initially impose that this industry is a monopoly with an incumbent that has the ability to offer differentiated products. The Hotelling line has length one. Consumers are uniformly located on this line with density one, implying that the total number of consumers is equal to one. Each consumer purchases either one unit or none.

Every consumer has a most preferred product specification θ, which we denote as the taste of this consumer. A product x different from the most preferred specification is valued lower in utility terms. In particular, the consumer's utility of this product equals

$$u - \upsilon|x - \theta|, \tag{1}$$

in which u is the utility a consumer assigns to a good that exactly matches its most preferred product specification θ, and υ denotes the degree of horizontal differentiation of this market.

If there are n different goods available at prices p_i and locations x_i, a consumer whose most preferred specification is θ will purchase one unit from some good if the maximum surplus of utility less price across the n different goods is non-negative. So we have the decision rule: Purchase one unit of the good satisfying

$$\max_i (u - \upsilon|x_i - \theta| - p_i) \geq 0.$$

The incumbent firm can offer different products with different tastes, but with every different product each time a set up cost s, has to be incurred. Production costs are linear with variable cost c, so that total costs of product i equals

$$f(q_i) = s + cq_i,$$

where q_i is the quantity of product i. The incumbent chooses the number of different products, n, and the corresponding output prices, p_i, such that profits are maximized:

$$\max_{n,p_1,\ldots,p_n} \left(\sum_{i=1}^{n} (p_i - c) q_i(n, p_1, \ldots, p_n) - ns \right).$$

The quantities q_i will be specified below for each specific situation considered.

2.1. Initial analysis of the incumbent problem

Let us first ignore the possibility that another firm enters with the additive manufacturing technology. Hence, in such a monopoly situation, we consider an incumbent offering n different products. Consumers will buy from this firm if their taste is sufficiently close to the taste of one of the products of this firm. Given that each consumer maximally buys one item of only one product of this firm, a consumer will only consider buying that product of which the corresponding taste is most close to his taste. Therefore, to maximize demand it pays for the firm to minimize the difference between the taste of the consumer that is most far away from the taste of the product that this consumer prefers. If one type of product would be offered, the product location minimizing this difference would be location $1/2$. If the number of different products were two, the locations minimizing the distance between the most far away consumer and one of the products would be the locations $1/4$ and $3/4$. It follows that for n different products the product locations are $1/2n$, $3/2n$, …, $(2n-1)/2n$, respectively. Since there is also no difference in the cost parameters c and s of the different products, the situation is symmetric among the different products. It follows that optimal output prices, p_i, are equal. We denote the resulting single output price by p_I, where the subscript I refers to the incumbent.

There can be two different situations:

- *No full market coverage:* the firm determines the product price such that for some consumers the products are too expensive so that they