3D Printing in Supply Chains

3D printing, also known as additive manufacturing, is a new manufacturing technique that is based on producing a product layer by layer. This technique contrasts with traditional manufacturing techniques, such as milling, forging, and welding. 3D printing has received significant and growing attention in recent years by different countries such as the United States, Japan, India, France, China and the Netherlands. Manufacturers that have historically utilized traditional manufacturing techniques are also investing in 3D printing. General Electric and Disney are two prominent examples.

According to a Gartner poll, 65 percent of supply chain professionals aim to invest in 3D printing during the next five years (Alec 2016). Therefore, in our paper, we propose and analyze stylized game-theoretic models of a simple manufacturer-retailer supply chain for a single product, where 3D printing is available. We consider (1) the natural case where the manufacturer may adopt 3D printing to supplement/replace traditional manufacturing techniques, and (2) a novel arrangement where the retailer may utilize 3D printing. We also study the following question: for the same parameter values, which scenario is more profitable for each firm and the supply chain as a whole.

**Manufacturer adopting 3D printing**: 3D printing can potentially decrease manufacturing variable cost. Conner et al. (2014) propose a framework to understand where 3D printing is economically feasible. The obstacles of adopting 3D printing, however, are the limited capacities of 3D printers and necessary investments in developing 3D plans. In our study, in addition to traditional manufacturing, the manufacturer can invest a fix cost to develop 3D plans and procure a certain number of 3D printers, before the production season, to manufacture the products. Therefore, in this scenario, the trade off is between an investment cost in 3D printing and a lower manufacturing cost.

**Retailer adopting 3D printing**: A key benefit of 3D printing is the fact that a retailer is able to install 3D printers in store and directly manufacture the products. This is a unique disruptive business phenomenon that enables the supply chain to be more responsive to uncertain demand.
To capture this benefit, we let the number of 3D printed products be a function of demand, which means the retailer can 3D print the products after demand uncertainty is resolved. The retailer can still order manufactured products, which allows the retailer to take advantage of possibly lower manufacturing wholesale prices, and at the same time to take advantage of the features of 3D printing to be more responsive to demand. Furthermore, if the retailer procures 3D printers, a fixed cost of developing 3D plans is incurred by the manufacturer. Under this scenario, the key trade off we study is between lower manufacturing wholesale prices and being more responsive to demand.

The following is a summary of our main findings and contributions to the operations management literature. (1) To the best of our knowledge, we are the first to analyze the impact of 3D printing on a supply chain. The unique characteristics of 3D printing result in its potential adoption by either the manufacturer or retailer, resulting in new models of cash, material and information flows. (2) For the case where the manufacturer may adopt 3D printing, we analytically derive the equilibrium of the interaction between manufacturer and retailer. We show that a necessary condition for the manufacturer to adopt 3D printing is that the unit 3D printing cost must be at most the unit cost of traditional manufacturing. Furthermore, the fixed cost of developing 3D printing plans from the traditional manufacturing plans must not be too costly. Production will be either 3D printed or produced traditionally, with no hybrid solution possible. Finally, if 3D printing is economically feasible for the manufacturer to utilize, then it benefits both the manufacturer and retailer, with respect to a benchmark system. (3) For the case where the retailer may adopt 3D printing, we analytically solve the retailer’s subproblem characterizing his behavior. We can then solve for the equilibrium under the additional assumption of uniformly distributed demand; accompanying numerical results, including for a normal distribution of demand, indicate that our analytical results closely mirror the actual equilibrium. Interestingly, 3D printing may be adopted even if the unit printing cost is more than that of traditional manufacturing; this is due to the increased responsiveness of the 3D printers at the retailer location, allowing a make-to-order strategy that is not possible at the manufacturer. We show that there are many economic and competitive scenarios
where the retailer’s adoption of 3D printing leads to improved profit outcomes for both the retailer and manufacturer, with respect to a benchmark system. Finally, in contrast to the case where the manufacturer adopts 3D printing, it is possible to have a hybrid equilibrium where traditional manufacturing and 3D printing are utilized in tandem. (4) Comparing the scenario where the manufacturer adopts 3D printing to that where the retailer adopts 3D printing, we learn that the manufacturer and the entire supply chain always prefer the retailer adopting 3D printing. The retailer’s preference, however, depends on problem parameters, and can prefer either manufacturer or retailer adoption of 3D printing. Notably, there exist supply chain parameters where both the manufacturer and retailer (and consequently the supply chain) prefer the retailer’s adoption of 3D printing, underscoring the importance of this novel combination of a retailer producing products using a new manufacturing technology.

References
