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Pricing and inventory decisions in the food supply chain with production disruption and controllable deterioration

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ABSTRACT

Food deterioration is becoming a crucial problem for most countries in the world, which may cause both economical losses and environmental damages. In this paper, a Stackelberg gaming model for a three-level food supply chain (consists of one retailer, one vendor and one supplier) with production disruption is established, which aims to study the optimal pricing, inventory and preservation decisions that maximize the individual profit. In the decentralized supply chain, upstream firms act as leaders and downstream firms as followers. Due to the mathematical complexity, an illustrative algorithm is developed to solve the problem. Numerical tests show that retailer's preservation investment not only benefits itself, but also benefits the vendor and the supplier. Comparing the optimal decisions to that in the 'forward integration' and 'backward integration' model, supply chain members' vertical cooperation helps to enhance the total profit. Meanwhile, the carbon footprint of the food supply chain is also studied. It is found that, vertical cooperation contributes to the reduction of carbon emission. In most situations, 'forward integration' outperforms 'backward integration' strategy because it incents the retailer to invest more in preservation and reduce food deterioration. Other managerial implications are also shown in the paper.

1. Introduction

Food deterioration is becoming a great challenge for food industry in many countries. According to Ghare and Schrader (1963), deterioration is defined as decay, change or spoilage through which the quality and/or the quantity of the items are decreasing. There are many reasons for the high perishable rate for food products such as long distance transport, inappropriate preservation methods, poor sanitation standards or rapid change in demand and supply. Approximately, 15% of foods are deteriorated in the food retailing sector (Ferguson and Ketzenberg, 2005). About one third of food produced is perished or wasted during consumption globally, which accounts for 1.3 billion tons (FAO, 2011). Also, as reported by Martin (2015), in China, more than 25% of fruit and vegetables are deteriorated during transportation, at wholesale markets and in shops.

Food deterioration causes both economical and environmental damages. It is prevalent in industry that companies in food supply chains (including food producers, food distributors and food sellers) are suffering from high losses due to food deterioration. As reported, food spoilage in Australia costs about $ 10,000,000 annually in its food sectors (Pitt and Hocking, 2009). In addition to the economic damages, food deterioration also worsens greenhouse gas emissions and brings significant damages to natural resources, such as air, water and climate (Alex, 2013). The carbon emission of food produced and wasted is approximately 3.3 billion tons, which follows the total emission of the USA and China (FAO, 2013). Thus, reducing food deterioration is significantly important and meaningful for both the economy and the environment.

To reduce food deterioration, an applicable option is to *invest in preservation technologies* during manufacturing, storage, transportation, and in the supermarkets (See Blackburn and Scudder, 2009; Dye and Hsieh, 2012; Hsu et al., 2010; Kouki et al., 2013; Musa and Sani, 2012). Spoilage of foods mainly stems from several environmental factors, including temperature, relative humidity, air velocity, atmospheric composition and sanitation procedures (Qin et al., 2014). Thus, suitable preservation environment is required to reduce product deterioration, which can be achieved by utilizing various preservation technologies. For example, supermarkets use refrigerators to preserve meat, milk, eggs, fruits and

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vegetables; use drying machines to keep the breads or cakes dry; use humidifiers to keep fruits or flowers hydrated. However, to achieve a lower deterioration rate, more investments are required. For example, to maintain a lower temperature, more electricity will be consumed. In real practice, managers need to balance the cost of product deterioration and that of preservation to enhance total profit, which is challenging but meaningful for supply chain management.

Vertical cooperation can also reduce food deterioration by reducing production/transportation lead times or optimizing production and sales strategies. In the food industry in China, some food companies choose to integrate with downstream sellers. This type of integration is called 'forward integration'. An illustrative example is *Suguo Inc.* (a leading supermarket in eastern China) operates several large distribution centers by itself. After procuring varies food products (including fresh fruits, vegetables, meat, milk) from upstream suppliers, they store the products in their refrigerated warehouses, and deliver the food products to its own sales stores. Besides, some companies choose the 'backward integration' strategy, which means the collaboration between upstream producers or raw material suppliers and vendors. Taking two fresh meat providers, *Shuanghui Inc.* and *Yurun Inc.* in China as examples, both of them cooperate with the upstream farms and distribute fresh pork to downstream retailers through their own distribution systems. Either type of cooperation strategy has its own advantages and disadvantages. As Lin et al. (2014) demonstrates, 'forward integration' enables firms to better control the retail price, and to respond more effectively to the changes in market demand changes. However, 'backward integration' enables firms to better control the production process and quality of the products.

In food industry, *production disruption* happens frequently and has significant impacts. For example, the Typhoon Goni that raged in Northern Luzon caused significant agriculture losses in Philippines, which result in the rise of vegetable prices and shortage of supply (Pia, 2015). As one of the biggest citrus growers in the world, Chinese citrus industry is suffering from typhoons repeatedly and greening disease, which once took more than 10% of the total production away during two seasons in 2014 (Cherrie, 2015). Disruptions in production processes at farms and food processors not only cause breakdowns in production, but also delays in supply chains. The upstream supply chain disruption can have significant impacts on downstream operations, and can cause purchasing cost increase, the shortage of supply or the damage to firms reputations. It is therefore critical to study the interactive decision making in the supply chains when the partners face production disruption.

Previous research on food deterioration mainly concentrate on the analysis of economical impacts, while seldom consider its environmental impacts. To solve the real world problems and to fill the gap in literature, this paper also analyzes the carbon footprint of the food supply chain. Specifically, the main research targets are summarizes as follows.

- To study the supplier's, the vendor's and the retailer's optimal prices, preservation investment and inventory decisions under the risk of upstream disruption and product deterioration.
- To investigate the impacts of critical parameters, such as producers reliability, inventory holding costs and production costs, to the optimal decisions, the maximum profits and carbon emissions.
- To investigate both the economical and environmental impacts of different cooperative strategies (i.e., forward integration and backward integration).

Focusing on the main research targets, a three level supply chain is modeled with a retailer, a vendor and a supplier. The main contributions of this paper are as follows. Firstly, a three level supply chain producing and selling deterioration products is studied, in which the supplier has production disruption risk and the retailer has controllable deterioration rate. The paper aims to fill the gap of supply chain management models for deteriorating items. Secondly, an illustrative algorithm is proposed to solve the complex multi-level gaming model. Thirdly, based on the numerical tests and sensitivity analysis, some important and interesting managerial insights for supply chain management of deteriorating items are identified, which can help to improve supply chain efficiency. Lastly, impacts of supply chain structure to the equilibrium results and carbon emission are studied.

1.1. Literature review

This research mainly involves three key elements: (1) preservation technology investment for deteriorating products (2) gaming models in multi-level supply chains with inventory decisions and (3) production disruption models with deteriorating products.

The first stream is about EOQ/EPQ models with product deterioration and preservation technology investment. In most literature, deterioration rate is assumed to be a constant parameter (see He and He, 2010; He and Wang, 2012; He et al., 2010; Liang and Zhou, 2011; Sana et al., 2004; Taleizadeh, 2014; Taleizadeh et al., 2013, 2015; Taleizadeh and Nematollahi, 2014; Thangam and Uthayakumar, 2009; Widyadana et al., 2011) or an exogenous time linked parameter (see Musa and Sani, 2012; Shah et al., 2013; Skouri et al., 2009; Tat et al., 2015). However, in real situations, deterioration rate can be reduced through various efforts such as procedural changes and specialized equipment installation. For products with high deterioration rates, such as fruits, vegetables or seafoods, firms usually adopt preservation technologies to reduce the deterioration rate. Some scholars found the links between investment and deterioration rate, and the reduced proportion of deterioration rate is a convex increasing function of the investment level (see Hsu et al., 2010; Dye and Hsieh, 2012). Blackburn and Scudder (2009) studied the optimal temperature control and delivery batch decision through the whole supply chain from picking stage, cooling stage to selling stage. Kouki et al. (2013) found that a continuous temperature control policy can be more efficient in warehouse management. Similar studies can be seen in Dye (2012, 2013), Dye and Yang (2016), He and Huang (2013), Hsieh and Dye (2013), Yang et al. (2015) and Zhang et al. (2016), which all consider firms preservation investment decisions under different conditions. Some people studied the preservation investment problem in a two level supply chain, such as Tayal et al. (2014) and Zhang et al. (2015). In this research stream, previous studies seldom consider multi-level supply chain problems with preservation investment.

The second stream refers to the gaming models in multi-level supply chains on inventory and pricing decisions. Lee et al. (2016) studied a two level supply chain with VMI policy and limited storage capacity. They found that an inventory holding cost sharing policy can coordinate the supply chain efficiently when the vendor's reservation cost is equal to the minimum cost of integrated supply chain. Yu et al. (2012) studied an integrated supply chain with one manufacturer and multiple retailers. Numerical tests showed that VMI can achieve a lower cost comparing to the decentralized supply chain. Ghiami et al. (2013) studied an integrated supply chain inventory system with one supplier and one retailer, in which the retailer's warehouse has capacity constraint and also can rent a warehouse with higher holding cost. Cárdenas-Barrón and Sana (2014) also studied an integrated supply chain