Master's Thesis of Operations Management

Impact of bullwhip effect on dynamic pricing for perishable produce: price surge and downfall in agricultural supply chain

농산물 동적 가격 책정에 대한 채찍효과의 영향: 농업 공급망의 가격 급등 및 하락

February 2023

Graduate School of Business
Seoul National University
Operations Management Major

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Master of Science in Business Administration

February 2023

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Abstract

The majority of prior research on the bullwhip effect focused on unperishable products and assumed that their initial price is fixed (unless intentionally discounted by promotion or sales) and supply of products is flexible. For example, in the beer game, the impact of amplified demand variabilities in the supply chain is highlighted by a buildup of inventory and backorder for each player. However, in various industries, this is not the case. Price is determined by two factors, supply, and demand. Thus, an amplified variation in demand via bullwhip could cause a tremendous impact on price. This study focuses on the bullwhip effect for the agricultural supply chain, which utilizes dynamic pricing to determine the initial price. Because of the characteristics of inelastic supply and perishability, the bullwhip effect has an immediate and significant impact on the price of the agricultural supply chain. Thus, this study conducted an empirical research on a case study that is developed from a typical potato supply chain in South Korea, which utilizes a wholesale auction system for dynamic pricing. Results indicate that the bullwhip effect impacts price, which distorts downstream players' demand, which again impacts the bullwhip effect as a loop.

Keyword : Bullwhip Effect, Dynamic Pricing, Agricultural Supply Chain, Perishability, Inelastic Supply.

Student Number : 2021-20593

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Chapter 1. Introduction

One of the major problems in Korea's economy is the immense fluctuation in the prices of agricultural produce. Various news outlets refer to Korea's agricultural produce price as "Roller Coaster" where there is constant variation and fluctuation (Kwon, 2017, Lee, 2021, Lee and Jung, 2014). Figure 1 shows four agricultural types of produce: onion, cucumber, tomato, zucchini, and potato, annual price level fluctuation for year 2022, 2021, and the average between the two. As you can see, each produce shows significant fluctuation in price. There are no trends or consistency but constant variation and fluctuation in price for all 4 different types of produce.

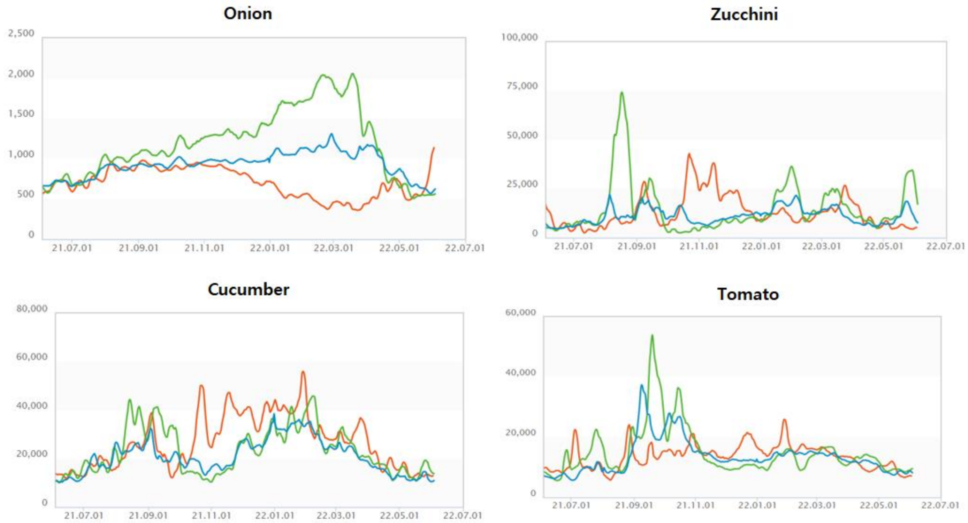
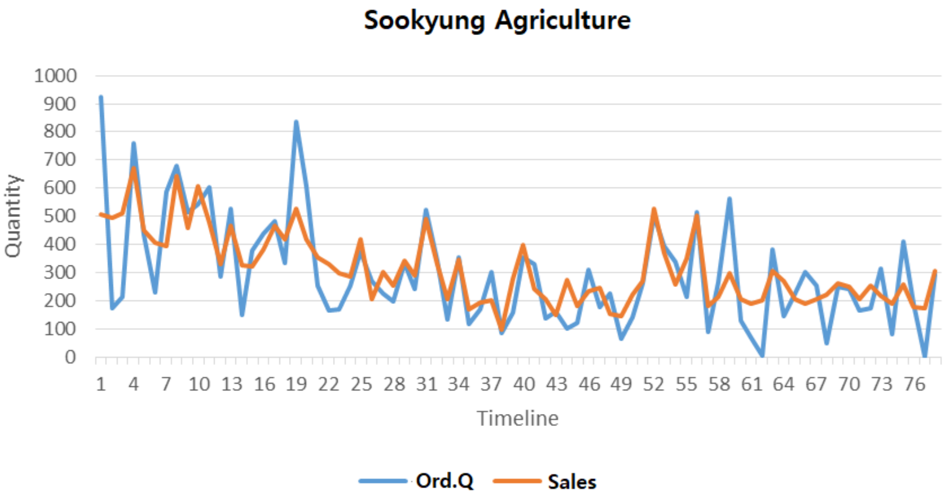


Figure 1: Agricultural produce annual price level for onion, cucumber, tomato and zucchini, year 2022 (blue), 2021 (orange) and the average between the two (green).

Price fluctuations are a major concern for the government and society. Farmers face significant fluctuations in their income. The majority of farmers work full-time. Thus, their main source of income is farming. Fluctuations in price cause farmers' income to be insecure, which causes anxiety for farmers (Lee, 2021). For wholesalers and retailers, consistent variation in the price will cause difficulty in their forecasting, marketing, operation, and finance, which impacts their profitability and optimization. Lee and

Jung (2014) state that the Korean government has implemented various initiatives and strategies to stabilize the price of agricultural produce. However, their initiatives are not effective and the price still shows significant fluctuation. These are some significant problems that are faced by the South Korean government and society, which cause major inefficiency and cost to the agricultural supply chain including farmers, consumers, and retailers.

Price is determined by two major factors, supply and demand (Parkin, Powell & Matthews. 2002). Thus, fluctuations in demand or supply can cause tremendous fluctuations in price. Graph 1 shows the daily order quantity and sales for a major wholesalers in Korea, who specialize in potatoes. As you can see, there are significant fluctuations in daily sales and ordering quantity. However, there is also a significant difference between the daily sales and the ordering quantity itself. At various dates, the variance of ordering quantity is significantly larger than the variance of sales. This highlights the amplification of demand, which shows a sign of a bullwhip effect.



Graph 1: The year 2022, June to August daily order quantity and sales for a Sookyung Agriculture, a major agricultural wholesalers in Korea, who specialize in potato.

The impact of the bullwhip effect has been intensively researched by various studies (Disney, S. M., & Lambrecht, M. R, 2008, Fransoo, J. C., & Wouters, M. J, 2000, Lee, Padmanabhan, and whang, 1997b & Sethuraman, K., & Tirupati, D, 2005). Amplified demand variation causes a significant build-up in inventory levels and back orders, especially for players in the upstream of the supply chain Lee, Padmanabhan, and whang (1997a). Numerous studies state that bullwhip causes significant cost and inefficiency throughout the entire supply chain. Various literatures state that price fluctuations cause the bullwhip effect. However, the impact and the consequence of the bullwhip effect on pricing have not been explored significantly.

In a free market, where dynamic pricing is utilized, price is determined by supply and demand (Parkin, Powell & Matthews. 2002). Thus, fluctuations or variability in demand can cause a tremendous impact on price. In a back-order situation, retailers will increase demand significantly Lee, Padmanabhan, and whang (1997a). Because of the bullwhip effect, this demand information will be amplified and cause the price to increase immensely for the wholesalers in the market. Built-up inventory will cause retailers to decrease their orders significantly (Lee et al, 1997a). Amplification of this effect will cause the price to decrease drastically. Thus, the bullwhip effect could cause a significant effect on price.

There has been significant prior research on the bullwhip effect and its impact on nonperishable products under fixed price and flexible supply circumstances Lee, Padmanabhan, and whang (1997b). However, the agricultural supply chain has three distinct characteristics: dynamic pricing, inelastic supply, and perishability. Because of these characteristics, the bullwhip effect causes a significant and immediate impact on the price for the agricultural supply chain. There are extremely lacking studies on the bullwhip effect and pricing, especially for perishable supply chains such as agricultural supply chains.

The bullwhip effect could impact the initial pricing of the product significantly. This variation in price significantly impacts the demand for the downstream players. Thus, these variations in downstream demand, caused by variations in initial price, could cause amplified distortion in the demand information for wholesalers, which further complicates the impact of the bullwhip effect via pricing. Thus, this study conducted in−depth empirical research about the bullwhip effect and price on Korea's agricultural supply chain by utilizing a case study.

Chapter 2. Literature Review

2.1. Definition of Bullwhip Effect

Lee, Padmanabhan, and whang (1997b) state that Procter & Gamble was the first to utilize the term bullwhip effect to explain the situation when the demand order variability is amplified as they reach the upstream of the supply chain. Lee, Padmanabhan, and whang (1997a) utilize four different players within the supply chain to explain the bullwhip effect and to show how, the key cause of the bullwhip effect, the information distortion is amplified in terms of order quantity and demand along the upstream of a typical supply chain. In a typical supply chain, which consists of a customer, retailer, wholesaler, and supplier, demand information follows upstream. Upstream supply chain members (wholesalers and suppliers) do not have the actual customer demand information; their decision on ordering quantity is based on the ordering quantity of the prior downstream player. Each player in the supply chain faces demand variability, causing variation and deviation from the actual customer order. Thus, as orders move up the supply chain, amplified order variability is formed, where downstream players have lower variability or discrepancy from actual demand than the upstream players. The majority of studies also support the definition of the bullwhip effect by Lee, Padmanabhan, and whang (1997a), the amplification of demand variabilities along the supply chain, which this study will utilize.

2.2. Measurement of Bullwhip Effect

Lee (2012) highlights that there are two ways to measure the bullwhip effect. The first method is measured by comparing the order variance and the demand variance (Lee, Padmanabhan, and whang, 1997a). The second method is measured by comparing the variance of order receipt and the variance of sales. The second method has been utilized by various empirical studies as the measure of the bullwhip effect. This is because obtaining actual demand and order quantity data (such as lost sales) is extremely difficult in practical settings (Blinder, 1981 & Cachon et al, 2007). Cachon et al (2007) utilized the amplification ratio to measure and quantify the bullwhip effect for their empirical studies. When the variance of demand divided by the variance of production is larger than 1, then the bullwhip effect is present. Also, if the variance of production subtracted by the variance of demand is larger than 0, the bullwhip effect is also present. Amplification ratio has been utilized by numerous empirical studies to measure the bullwhip effect for various industries (Shan, J., Yang, S., Yang, S., & Zhang, J, 2014, Chen, L., & Lee, H. L, 2012 & Isaksson, O. H., & Seifert, R. W, 2016).

$$\textbf{Amplification ratio} = \frac{\boldsymbol{V}[\,\textbf{Production}\,]}{\boldsymbol{V}[\,\textbf{Demand}\,]} > \mathbf{1},$$

Or

$$\textbf{if } \boldsymbol{V}[\,\textbf{Production}\,] - \boldsymbol{V}[\,\textbf{Demand}\,] > 0$$

Thus, this study will utilize Cachon et al (2007)' s amplification ratio to measure the bullwhip effect. Also, the comparison between the variance of order receipt and the variance of sales will be utilized (Blinder, 1981 & Cachon et al, 2007) instead of the comparison between order variance and the demand variance (Lee et al, 1997a).

2.3. Industries with Bullwhip Effect

Table 1 illustrates the strength and magnitude of the bullwhip effect in various wholesale industry levels within the U.S. (Cachon,

G. P., Randall, T., & Schmidt, G. M, 2007). Among various industry levels, wholesale industries were most vulnerable to the bullwhip effect, while retail and manufacturing industries showed less degree of the bullwhip effect. Among the wholesaler industries, drugs and druggist' sundries exhibited the highest magnitude of the bullwhip effect, with a 4.15 amplification ratio. Farm product raw materials, which is the agricultural wholesale industry, showed the second highest magnitude of bullwhip effect with a 3.45 amplification ratio.

Wholesale Industry	$V[Y]/V[D]$	$V[Y]-V[D]$
Aggregate wholesale series	1.14	0.0006
Apparel, piece goods, and notes	1.24	0.0039
Beer, wine and distilled alcoholic beverages	0.57	-0.0101
Chemicals and allied products	1.48	0.0025
Drugs and druggists' sundries	4.15	0.0164
Electrical and electronic goods	0.99	0.0000
Farm product raw materials	3.45	0.0285
Furniture and home furnishings	1.45	0.0027
Grocery and related products	1.39	0.0013
Hardware, and plumbing and heating equipment	1.17	0.0009
Lumber and other construction materials	1.11	0.0009
Machinery, equipment, and supplies	1.24	0.0019
Metals and minerals, for example, petroleum	1.50	0.0031
Miscellaneous durables goods	1.15	0.0010
Miscellaneous nondurable goods	1.42	0.0025
Motor vehicle and motor vehicle parts and supplies	1.11	0.0008
Paper and paper products	1.67	0.0034
Petroleum and petroleum products	1.35	0.0013
Professional and commercial equipment and supplies	1.07	0.0007

Table 1: Amplification Measure for industry Groups (1992−2005), Cachon, G. P., Randall, T., & Schmidt, G. M. (2007)

2.4. Cause of Bullwhip Effect

Lee et al (1997b) state that there are four major causes for the bullwhip effect: forecasting, order batching, price fluctuation, and shortage game/rationing. Forecasting requires to consider not only the history of customer demand but also factors such as long lead time and safety stocks. These variables cause the fluctuation in ordering quantity to be greater than the actual demand. Order batching causes spikes of demand instead of smooth and consistent demand. Price fluctuations such as discounts, coupons, and rebates cause "forward buying (Salmon, 1993)" which creates a discrepancy between the variation of the ordering quantity and the sales (consumption). A shortage game occurs when demand exceeds supply and suppliers are forced to ration their quantity to customers. Because customers know that suppliers will ration their supply, customers exaggerate their demand to secure more products. All of these factors cause an increased variation between the actual demand and order quantity, which is amplified for upstream players because of the bullwhip effect.

Paik & Bagchi (2007) conducted a statistical analysis and determined six factors as a cause for the bullwhip effect (demand forecast updating, order batching, material delays, information delays, purchasing delays, and level of echelons). Among these 6 factors, demand forecast updating, level of echelons, and price variations are the most significant. Bhattacharya & Bandyopadhyay (2010) conducted a literature review on operational and behavioral factors for the bullwhip effect. The study concluded that there is a total of 19 factors that causes the bullwhip effect. 5 factors, demand forecasting, order batching, price fluctuation, shortage game/rationing, and lead time are mentioned by various studies multiple times. Overall, various studies state that price fluctuation is one of the most significant causes of the bullwhip effect. Thus, it could be interpreted that price fluctuation causes a bullwhip effect.

2.4. Impact of Bullwhip Effect

Lee et al (1997b) utilize a case from Hewlett-Packard to explain how the amplified demand information variation could cause a significant increase in inventory level or backorder, especially for the upstream members of the supply chain. An increase in inventory level causes an increase in inventory cost, and back order allows for a loss in potential revenue. Also, back orders lead to an increase in lead time, which causes a decrease in customer service levels.

Manufacturers have to produce orders swiftly, which may result in a decrease in quality. Other inefficiencies such as misguided capacity plans, inefficient production schedules, and transportation have been researched significantly (Disney, S. M., & Lambrecht, M. R, 2008, Fransoo, J. C., & Wouters, M. J, 2000, Lee et al, 1997b & Sethuraman, K., & Tirupati, D, 2005).

Metters (1997) conducted a study to quantify the impact of the bullwhip effect on firms. The study focused on excess cost, seasonality, and demand variance which directly impact the profitability of the firm. The study highlighted that reducing the bullwhip effect could improve the profitability of the firm significantly. Thus, bullwhip causes massive cost and inefficiency not only to the entire supply chain but also to the individual firms significantly.

However, there is an area where the impact of the bullwhip effect has been not explored; price. Although price fluctuation is the cause of the bullwhip effect, there is no significant study that shows the bullwhip effect's impact on price. The majority of prior studies conducted their research on industries or products that has no fluctuation in price or assumed price is fixed unless intentionally discounted. Price is a significant factor for all members of the supply chain because it is the direct factor for the profitability of their firm and the entire supply chain. Also, under dynamic pricing, the bullwhip effect should have an immediate and significant impact on pricing.

2.5. Dynamic Pricing

Dynamic pricing is referred to the optimal selling price of products or services, where the optimal price could be easily and frequently adjusted (Boer, A. 2015). From basic economic principles, we could easily understand the logic of dynamic pricing. Davenant (1700) first developed the King-Davenant law which shows a demand curve for corn that highlights the fluctuation of price depending on supply and demand. Lean Walras founded the concept of price equilibrium, which calculates the optimal price under certain supply and demand conditions (Friedman, 1955). Evans (1924) stated that the "demand is not only a function of price but also of the time-derivative of price". Consumers not only consider the current price but also the time-derivative aspect of price, which is the anticipation of the change in price. Thus, even if the current price is extremely high, if the customer expects the price to further increase, then their demand would also increase as well. Boer (2015) states that the demand curves were first developed and utilized for various products to support macroeconomic theories on price, supply, and demand, instead of profit maximization for businesses. Thus, under typical dynamic pricing conditions, supply and demand are the key factors that determine the optimal price.

2.6. Bullwhip Effect and Pricing

There has been numerous research on the bullwhip effect and pricing. Bhattacharya & Bandyopadhyay (2010) states that price fluctuation is the cause of the bullwhip effect and industries should utilize strategies such as CRP, Every Day Low Pricing, and activity-based pricing to avoid price fluctuation and discount. Tai, Duc, & Buddhakulsomsiri, (2019) showed that, under certain conditions, the bullwhip effect could be stronger or weaker depending on whether or not the price is considered. The study stated that lead time impacts the bullwhip effect by the "appearance" of price. The majority of past papers (Lee et al, 1997b, Metters, 1997, & Bhattacharya & Bandyopadhyay, 2010) focus on price as a cause or just a factor that influences demand by discounts such as bulk purchase or seasonality. However, no paper explains the effect, process nor magnitude of the bullwhip effect's impact on pricing.

As stated before, prior research assumed that there was no fluctuation in the price unless intentionally discounted. In various industries, prices always fluctuate depending on the market

(Borenstein, & Shepard. 1993, Pupavac, D. 2016, Stuermer, M. 2018, Nerlove, M. 1958). However, the bullwhip effect has a major impact on the market by amplifying distorted demand information (Lee et al, 1997a). As highlighted by various papers, the bullwhip effect's amplification of demand for upstream players would have a significant impact on the determination of optimal prices under dynamic pricing conditions. Thus, this paper examines the impact of amplified variation of demand and price via the bullwhip effect, throughout the entire supply chain.

2.7. Inelastic Supply

The majority of wholesale industries that utilize dynamic pricing often have an inelastic supply curve (Konishi & Nishiyama, 2016). It is well known that industries such as oil, gas, minerals, and agriculture utilize dynamic pricing to determine their optimal price at the wholesale level and has an inelastic supply (Borenstein, & Shepard. 1993, Pupavac, D. 2016, Stuermer, M. 2018, Nerlove, M. 1958). An inelastic supply curve simply refers to a situation where a product's percentage change in supply is less than the percentage change in price (Samuelson & Nordhaus, 2001). To counteract demand variation, manufactured products have various strategies to increase or decrease their immediate capacity temporarily, such as spare capacity or overtime utilization (Lee, Padmanabhan & Whang. 1997a). However, inelastic supply products do not have the ability to immediately change their capacity to match the current demand because their short-term factors of production are extremely limited (Parkin, Powell & Matthews. 2002). Their production lead times are extremely long, require significant investment to increase or decrease their capacity, and almost always utilize 100% of their capacity at all times. A mismatch between demand and supply leads to a significant change in price. (Parkin, Powell & Matthews. 2002, Samuelson & Nordhaus. 2001). Thus, inelastic supply industries are more vulnerable to demand variation and price is significantly volatile to changes in demand.

2.8. Perishability

Out of wholesale industries that utilize dynamic pricing, agricultural wholesale industries have one significantly different characteristic; product perishability. Agricultural produce, such as fruits and vegetables, has a limited shelf life. These produce will rot after a certain amount of time, which will be salvaged or discarded. Nonperishable goods allow any players within the supply chain to hold inventory without significant risks such as overage cost (Lee, Padmanabhan & Whang. 1997a). Because of the low risk of salvage, each player in the supply chain can defend against demand variability by increasing their safety stock and inventory level. However, as highlighted by the newsvendor model, perishable goods have a direct limit on inventory holding time, the shelf life of the product. Also, unsold products have to be discarded or sold at a salvage value and new products must be ordered (Qin, Y., Wang, R., Vakharia, A. J., Chen, Y., & Seref, M. M. 2011). Because of the risk of overage cost, players do not have the ability to purchase and hold significant inventory or safety stock to defend against demand variability. Their only option is to constantly change their ordering quantity to match fluctuating demand (Cancian, F. 1980). Thus, perishable goods are more vulnerable to demand and price variations because of the limited concept of inventory.

Also, the quality of fresh produce decreases over time (Peña, Bas & Maldonado, 2021). Thus, players within the supply chain desire to swiftly send their produce down the supply chain and do not desire long inventory holding time. Therefore, the transfer of the inventory and price is quick, which leads to a direct and immediate impact on the supply chain.

2.9. Agricultural Supply Chain and Bullwhip Effect

As stated above, the agricultural wholesale supply chain has two key characteristics; dynamic pricing (inelastic supply) and perishability. Thus, agricultural wholesale supply chains are extremely vulnerable and volatile to fluctuations in demand and price. There were few studies that examined the impact of the bullwhip effect on the agricultural supply chain. Peña, Bas & Maldonado (2021) conducted a study that highlighted the impact of the bullwhip effect on the quality and waste of food. They identified that the demand information update, product deterioration level, and the number of intermediaries are the key factors that cause the bullwhip effect in the perishable supply chain. Ji, H. (2016) research the effectiveness of "Farm – Supermarket Docking" on the bullwhip effect. The study states that the farm–supermarket docking method could reduce the impact of the bullwhip effect more effectively than the conventional trading method when the information-sharing mechanism is optimized. The majority of prior studies focused on information-sharing optimization, and the quality aspect of the agricultural supply chain, instead of the impact of the bullwhip effect on agricultural produce price.

Chapter 3. Conceptual Model

3.1. Model Background

Figure 2 shows us a diagram that summarizes Korea's agricultural supply chain that highlights the bullwhip effect and price. First, orders are sent upstream from the customer to the retailer and then to wholesalers. However, during this flow of demand information, there is an amplification of demand variation because of the bullwhip effect. Thus, the variation of the wholesaler order quantity is significantly larger than the variation of the actual customer demand, which causes significant demand information distortion. With this significantly distorted demand information, the wholesaler determines the price of the agricultural produce by dynamic pricing. Agricultural markets in Korea utilize auction systems to determine the optimal price for the produce, which is sent directly by farmers. Thus, depending on the supply from the farmers and the ordering quantity of the wholesaler, the initial price of agricultural produce is determined. When the initial price is determined, the price and the actual produce naturally flow to the downstream players accordingly. Wholesalers add their markup to the initial price and sell it to the retailer. Retailers also sell their produce to customers with their markup amount added to their purchase price. This process is then repeated once the customer orders produce from the retailers.

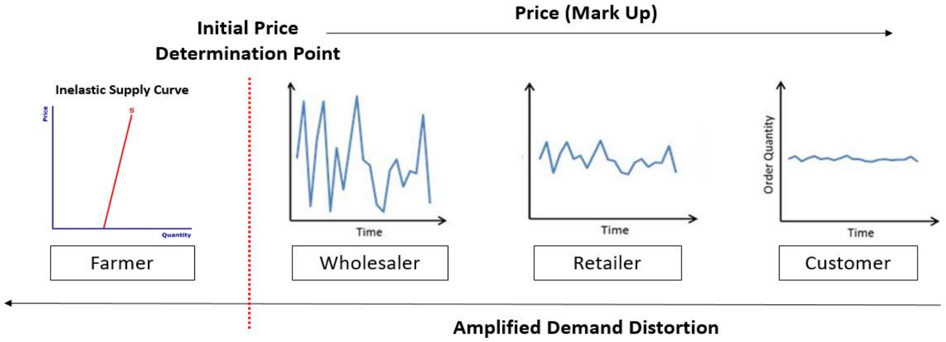


Figure 2: Summary of Agricultural Supply Chain in Korea that shows bullwhip effect, determination and transfer of price.

3.2. Terminology: Sales vs Demand, Production vs Order Quantity

This model will utilize the second definition of Lee (2012), which is the measurement of the bullwhip effect by comparing between the variance of order receipt and the variance of sales, for practical reasons. Actual order or demand data is extremely hard to obtain. Demand information must include factors such as lost sales. Also, order information must include lost order receipt quantity. However, the majority of wholesalers and retailers do not record these information, which forces us to utilize the second definition. Blinder (1981) and Cachon et al (2007) both utilized the second definition during their empirical studies to conduct more practical and implementable research. Cachon et al (2007) utilized the industry's sales as a proxy for its demand. The study stated that sales and demand have similar volatility in most cases. Also, there were eight industries where the variance of demand was more than twice the variance of sales, no industry had the reverse. All eight industries had common characteristics of make-to-order or customized goods, which agriculture is not. Also, interviews from both wholesalers and retailers who provided the data, stated that there was no loss in sales by a lack of inventory. Thus, this study will utilize sales as a proxy for demand.

Cachon et al (2007) defined "production" as the "inflow of material to the industry". Although the word "production" could be utilized to generalize all different types of industries, there is no "production" of produce within the agricultural industry. Unlike production, agricultural supply is fixed within the short term because of inelastic characteristics. Also, because of the auction system, wholesalers compete with other competitors with prices by bidding. Thus, there is no order placement, lead time, or lost order from a manufacturer to a wholesaler. There is only a confirmed receipt of the ordered quantity for wholesalers. Therefore, for easier comprehension, this study will utilize the term order quantity instead of production.

3.3. Model Notation

Table 2 shows all the model notation that will be utilized in the conceptual model. d_t^w is the total wholesaler's demand and d_t^r is the total retailer demand at day t.$V(d_{t-1}^w)$and $V(d_t^r)$ each represents the variance of wholesaler's demand at day $t-1$ and retailer's demand at day t. Y_t^w is the the wholesaler's order quantity and Y_t^r is the retailer's order quantity at time t. $V(Y_t^w)$ and $V(Y_t^r)$each represents the variance of wholesaler's and retailer's order quantity at day t. The summation of all retailer order quantity at day t, $\sum Y_t^r$, represents the wholesaler's demand, d_t^w.

d_t^w	Total wholesaler's demand at t	$d_t,\ d_{t-1}$
d_t^r	Total retailer's demand at t	
$V(d_{t-1}^w), V(d_t^r)$	The variance of wholesaler's demand at $t-1$ / Retailer's demand at t	$V(d_{t-1}^w \ldots d_{t-2}^w), V(d_t^r \ldots d_{t-2}^r)$
Y_t^w	Wholesaler's order quantity at t	
Y_t^r	Retailer's order quantity at t	**Total retailer order quantity $\sum Y_t^r$ represents wholesaler's demand d_t^w*
$V(Y_t^w), V(Y_t^r)$	The variance of Total wholesaler's / retailer's order r quantity at t	$V(Y_t \ldots Y_{t-2})$
p_t^w	Auction Price at t	
p_t^r	Retailer purchase price at t	$where\ p_t^r\ is\ correlated\ to\ p_t^w$
$V(p_t^w), V(p_t^r)$	The variance of auction price / retailer purchase price at t	$V(P_t \ldots P_{t-2})$
BE	Information distortion (Bullwhip Effect) for both wholesaler-retailer / retailer-customer relationships.	$BE = \frac{V(Y_t^w)}{V(d_{t-1}^w)}, BE = \frac{V(Y_t^r)}{V(d_t^r)}$

Table 2: Model notation for the conceptual model.

p_t^w and p_t^r are different prices. p_t^w is the initial price that is determined by auction. Thus, it is the price that wholesaler pays to the farmers. p_t^r is the price that retailer's purchase price from wholesaler. Wholesalers adds their markup to p_t^w, which becomes p_t^r. Thus, assuming the wholesaler's markup is reasonable constant, p_t^r is correlated to p_t^w. $V(p_t^w)$ and $V(p_t^r)$ each represents the variance of auction price and retailer purchase price at day t.

3.4. Bullwhip Effect Measurement

Cachon et al (2007)'s amplification ratio, $\frac{V[\text{Production}]}{V[\text{Demand}]}$, is utilized to measure bullwhip effect. However, following Blinder (1981) and Cachon et al (2007), amplification ratio is modified $\frac{V[\text{order receipt}]}{V[\text{sales}]}$. There are two distinct bullwhip effect in this model, wholesaler–retailer and retailer–customer bullwhip effect. Thus, both bullwhip effect, $\boldsymbol{BE}$, is measured by $\frac{V(Y_t^w)}{V(d_{t-1}^w)}$ for wholesaler–retailer and $\frac{V(Y_t^r)}{V(d_t^r)}$ for retailer–customer.

The reason behind $\boldsymbol{BE} = \frac{V(Y_t^w)}{V(d_{t-1}^w)}$ instead of $\boldsymbol{BE} = \frac{V(Y_t^w)}{V(d_t^w)}$ is because bullwhip effect measures the amplification of demand information (quantity) for a particular order instead of difference between order receipt and sales on that particular day. In Korea's agricultural wholesale market, auctions are conducted between late night and in the early morning. Thus, the purchasing details and the order receipt information for wholesalers are updated in the morning. However, wholesalers forecast the sales and determines the desired purchasing quantity based on the prior sales and demand information. Thus, the sales information from the day before, $\boldsymbol{V(d_{t-1}^w)}$, is utilized to measure the bullwhip effect, which the amplification of demand (order quantity) information.

Cachon, G. P., Randall, T., & Schmidt, G. M. (2007) states that the bullwhip effect is exhibited by an industry when the variance of its production is greater than the variance of its demand. Bullwhip effect is an amplified demand information variation. Thus, even if retailer–customer bullwhip effect is larger than wholesaler–retailer bullwhip effect ($BE = \frac{V(Y_t^r)}{V(d_t^r)} > BE = \frac{V(Y_t^w)}{V(d_{t-1}^w)}$), as long as there is amplification in wholesale ($BE = \frac{V(Y_t^w)}{V(d_{t-1}^w)} > 1$), bullwhip effect is present.

3.5.1. Model Propositions

Figure 3 shows the framework that this study will utilize. The model has three variables, bullwhip effect, price variability, and distortion in demand information, in a circle. Thus, there are three propositions based on the model.

Proposition 1: The bullwhip effect has a significant and position impact on price variability.

Proposition 2: Price variability has a significant and positive impact on the distortion of demand

Proposition 3: Distortion on demand has a significant and positive impact on the bullwhip effect.

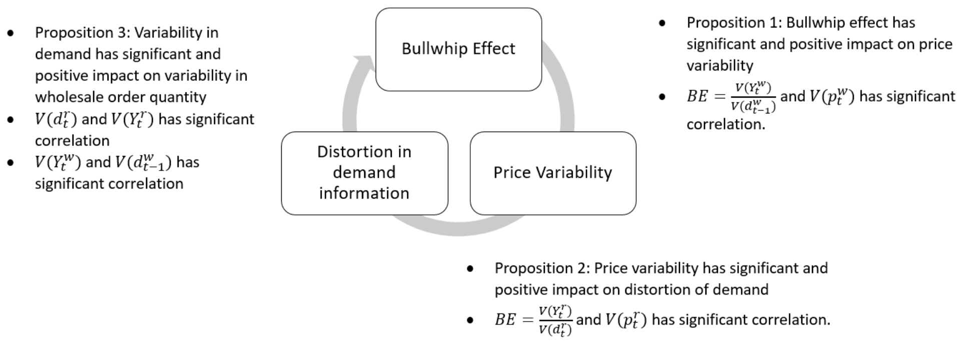


Figure 3: Summary of the conceptual model that highlights the relationship and direction of the three variable: Bullwhip Effect, Price Variability and Distortion in Demand Information.

3.5.2. Proposition One

Figure 4 illustrate the initiation of the model, where bullwhip effect impacts fluctuation in price. Based on the retailer's most recent demand, $\boldsymbol{d_{t-1}^w}$, wholesaler determines their purchasing quantity in the market, $\boldsymbol{Y_t^w}$. Also, based on $\boldsymbol{Y_t^w}$, the price for the agricultural produce is determined because of characteristics of dynamic pricing and the law of supply and demand. An increase in retailer's demand $\boldsymbol{d_{t-1}^w}$ will cause wholesaler's ordering quantity $\boldsymbol{Y_t^w}$ to increase in order to replenish their inventory and to prevent lost sales. Also, wholesaler will have to compete for more quantity, which will force wholesalers to bid higher prices to secure their quantity in the market. Therefore, their initial purchasing price, $\boldsymbol{Y_t^w}$, will increase, and vice versa.

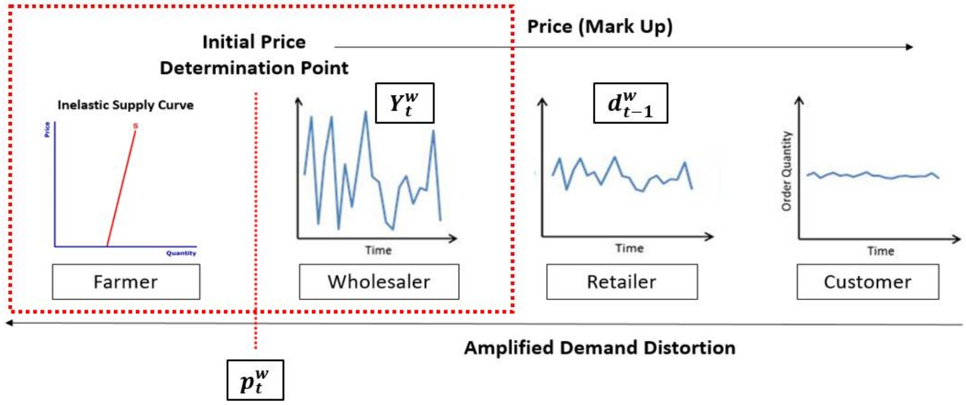


Figure 4: Summary of Agricultural Supply Chain in Korea that highlights the initiation of the model, where the wholesalers and the farmers determine their price at the market.

However, the bullwhip effect will escalate the fluctuation in price significantly. Figure 5 and 6 shows both situations where the bullwhip effect leads to a price surge and the downfall of the produce. Figure 5 shows a significantly amplified increase in order quantity for wholesalers, where in the market, their demand is increased significantly, which shifts the demand to the right and increase price immensely because of the inelastic supply characteristics (Parkin, Powell & Matthews. 2002, Samuelson & Nordhaus. 2001). Also, Figure 6 shows a significantly amplified decrease in order quantity, which decrease demand in the market significantly, which shifts the demand to the left and decreases the price drastically (Parkin, Powell & Matthews. 2002, Samuelson & Nordhaus. 2001). Thus, the bullwhip effect, by amplification of order quantity, could impact the initial price of the produce significantly, which leads to the first proposition: The bullwhip effect has a significant and position impact on price variability.

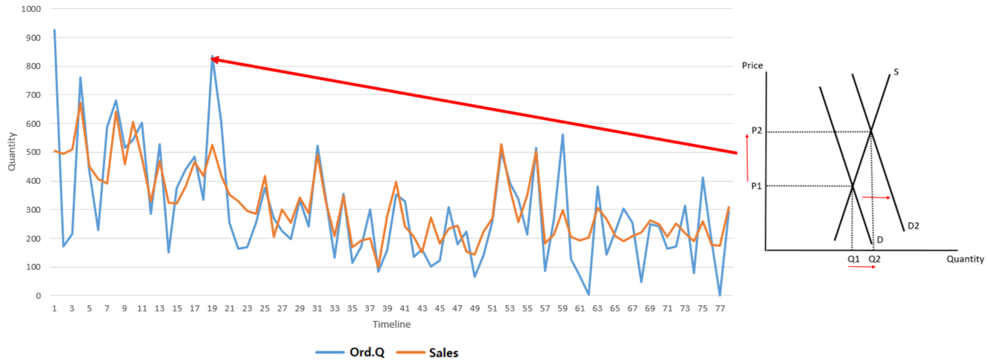


Figure 5: Explanation of how bullwhip effect increases price significantly with amplified demand information, Sookyung Agriculture.

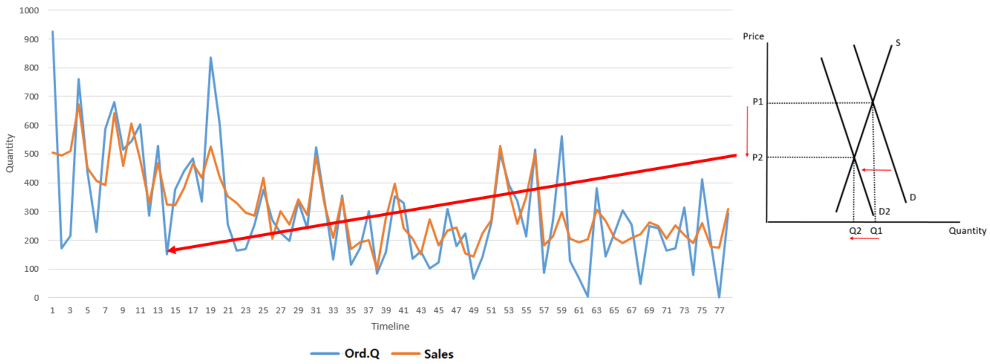


Figure 6: Explanation of how bullwhip effect decrease price significantly with amplified demand information, Sookyung Agriculture.

3.5.3. Proposition Two

After wholesalers obtain their produce from the market, they sell their produce to retailers at a marked up price, p_t^r. As shown in figure 7, depending on the price, p_t^r, and the demand from the customers, d_t^r, retailer's will determine their ordering quantity, Y_t^r. It is obvious that retailer's demand and ordering quantity will have a positive and significant relationship. Retailers will need to restock their inventory at a similar rate as demand to optimize their inventory and risk. However, fluctuation in their price, p_t^r, will influence their ordering decision significantly as well. Increase in p_t^r would increase the risk for retailers significantly, which will decrease their ordering quantity, Y_t^r. Also decrease in p_t^r would allow retailer's to increase their profit levels, provide discount opportunities for customer and lower the risk of inventory, which will increase the ordering quantity, Y_t^r. Prior studies has concluded that price fluctuation cause significant distortion in demand, which results in bullwhip effects (Salmon. 1993 & Lee et al. 1997). Thus, our second proposition, price variability has significant and positive impact on distortion of demand, is created.

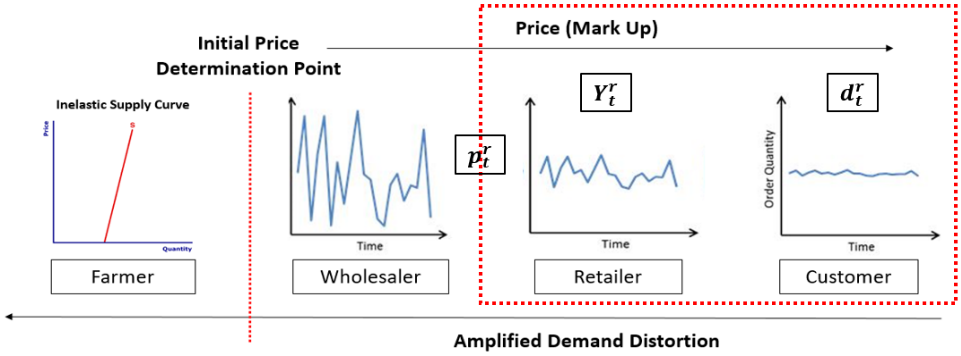


Figure 7: Summary of Agricultural Supply Chain in Korea, where retailer determines their ordering quantity depending on wholesaler's price and customer's demand.

3.5.4. Proposition Three

Figure 8 shows the flow of the distorted demand information from downstream to upstream of the supply chain. As stated before, the total retailer order quantity $\sum Y_t^r$ represents wholesaler's demand d_t^w. Thus, distorted retailers order quantity, Y_t^r, will further distort wholesalers' demand d_t^w significantly. Based on the distorted information, wholesaler determines their ordering quantity, Y_t^w , which cause significant bullwhip effect. and the cycle repeats again. Thus, proposition 3, distortion on demand has a significant and positive impact on the bullwhip effect, is created.

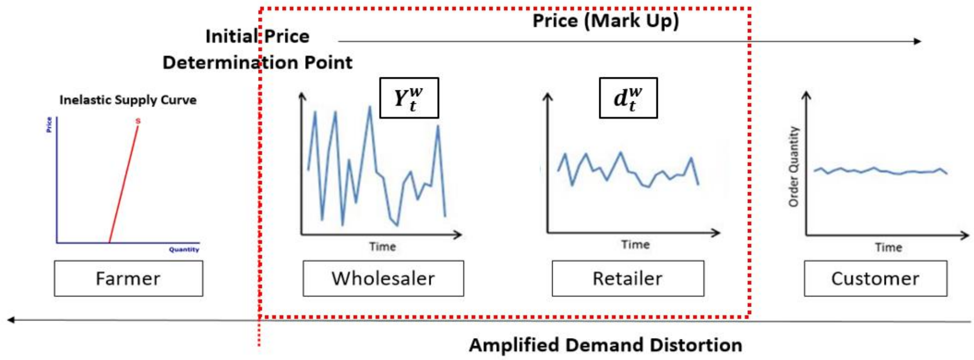


Figure 8: Summary of Agricultural Supply Chain in Korea, where wholesaler determines their

ordering quantity using distorted demand information from retailers.

Chapter 4. Methodology

The study conducted an empirical research on a case study that is developed from a typical potato supply chain in South Korea, which utilizes a wholesale auction system for dynamic pricing. The data obtained to conduct this research is from the Garark wholesaler market and because over 50% of Korea's agricultural produce is supplied through the wholesale market system in Korea, this case study could be generalized to the Korean agricultural supply chain and to any global supply chains that utilize auction system to dynamically determine the initial price of their agricultural produce.

Out of various different types of produce, the potato was chosen because of stable supply, consistent demand, and constant margin added to the price. Supply is a major factor to determine the price. Thus, factors such as supply shock will influence price significantly, which will deter our results and interpretation for this research. For the potato market in Korea, there has been no report of major potato shortage or supply shocks for the past 3 years. For this research, we desire that the cause of fluctuation in demand to be limited to price and bullwhip effect, instead of factors such as trends and substitutes. The USDA Foreign Agricultural Service (2018) states that overall potato consumption in Korea will remain steady. Korea's per capita potato consumption has been constant for the past five years and they expect to maintain a similar level for the next 5 years. Initial market price p_t^r and wholesaler's price to retailer p_t^w has to be correlated. This means that margins added by wholesaler has to be consistent. Interviews from the wholesalers and retailers state that the margins they impose on their products are not random but majorly constant. Thus "Potato" is a suitable produce to conduct this research.

Chapter 5. Data Collection and Analysis

5.1.1 Data Collection

Data is based on wholesalers that operate in the Gararк market. Garark Market was constructed by the Korea Government for farmers to obtain a fair price for their produce by utilizing an auction system. Garak Market, in terms of sales and volume, is the largest operating wholesale marketing in the world with 2,500,000 Tons of produce distributed annually. Garark Market has a market share of 34.3% in Korea's Wholesale Market Industry and provides services to 50% of Seoul's fruits and vegetables, livestock, and fisheries. Garak Market has three major sections, fruits, and vegetables, livestock, and fisheries, with fruits and vegetables being the largest with 2,097,480 tons (Fruits 473,997 Tons & Vegetable: 1,623,483) which equals to 4,115,410,000,000 Won traded annually.

5.1.2. Wholesaler's Data

3-month data (June, July, and August) including sales, order quantity, inventory, salvage, and date were received from two wholesalers within the Garark wholesale market; Sookyung Agriculture and Yewon Agriculture. Both are within the top 5, in terms of their sales, for potatoes within the Garark market. Because their purchasing price is undisclosed, we had to obtain the information from the corporation of the Garark wholesale market. During the 3 months, 971 transactions were made from Sookyung Agriculture and 702 for Yewon Agriculture. Because purchasing price for each auction is different, the average price per day was utilized. We split the data into 3-day terms. This is because the wholesaler market in Korea only operates 6 days a week. However, interviews from wholesalers suggest that they receive an average of two orders a week from their major vendors and retailers. Thus, measuring in a 3-day term seems most suitable for the Korean agricultural wholesale industry.

5.1.3. Retailer's Data

3-month data, including purchase price, purchase quantity, and inventory situation, were received from a renowned Gamjatang franchise restaurant, which specializes in Korean potato meat soap, and from a local supermarket, which specializes in fruits and vegetables. Both purchase from a Garark market wholesaler (Sookyung Agriculture) once a week. They do not know the exact demand quantity from customers but from their inventory and purchase detail, demand was calculated. There was no disposition (salvage) of potatoes in both stores.

5.2. Data Validation

Because 3-month data may not represent the typical potato industry, F-test and Post hoc analysis are conducted to check if the price differs significantly between the months. Appendix 1 shows us the results of the F-Test and Post hoc analysis conducted for the annual price of potatoes (October 2021 ~ September 2022). The daily average price of potato was obtained from the Cooperation of Garark market and allocated to each month. Overall the ANOVA test tells us that depending on the month, the price of potatoes is significantly impacted. However, the Post hoc test tells us that April and May are the only months that cause a significant difference. April and May have a p-value of 0 for all the other months. However, all the other months have a p-value larger than 0.05 between each other except for April and May. Thus, June, July, and August could be used to represent the typical potato price for the year except for April and May.

5.3.1. Data Analysis

Pearson correlation analysis is utilized in this study to test and evaluate the strength and direction of linear relationships between the variables for each perception. Although regression analysis is a potential alternative to analyze the model, Pearson correlation analysis is chosen because of its ability to constitute the numerical connections between the variables, which is a key insight when examining and verifying the relationship between the various variables.

5.3.2. Correlation vs Causality.

Because the study only performed correlation analysis, the direction and the causality of the model could be a concern. Although each proposition was explained in detail, supporting evidence for the direction of the model is included.

5.3.3. Proposition 1: Bullwhip effect is the causation for price variability

For price variability to cause a bullwhip effect, an increase in price should decrease the wholesaler order quantity and a decrease in price should increase the wholesaler order quantity, causing further deviation from demand and increasing in bullwhip effect. Thus, order quantity and price must have a negative and significant relationship for this causation to occur. However, our analysis shows a different story.

Table 3 shows the result of the regression analysis that highlights the relationship between the discrepancy from demand and price. Where discrepancy from demand is = Order quantity, $\boldsymbol{Y_t^w}$ – demand, $\boldsymbol{d_t^w}$. Because we know that demand and ordering quantity has a significant correlation, the discrepancy between the two is utilized to measure the increase or decrease in wholesaler order quantity. The results show us a p−value of 0.499, which is immensely larger than 0.05. Thus, the analysis shows us that price does not have a significant relationship with order quantity for wholesalers. Because the precondition for the causation, price variability is the causation of the bullwhip effect, is not statistically significant, the study suggests the direction of the correlation to be the bullwhip effect causing price variability to fluctuate significantly.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.099[a]	.010	-.011	4223.47821

a. Predictors: (Constant), Discrepancy

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	8275247.3	1	8275247.3	.464	.499[b]
	Residual	838375104.3	47	17837768.2		
	Total	846650351.6	48			

a. Dependent Variable: Price

b. Predictors: (Constant), Discrepancy

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	28627.421	623.920		45.883	.000
	Discrepancy	-1.986	2.916	-.099	-.681	.499

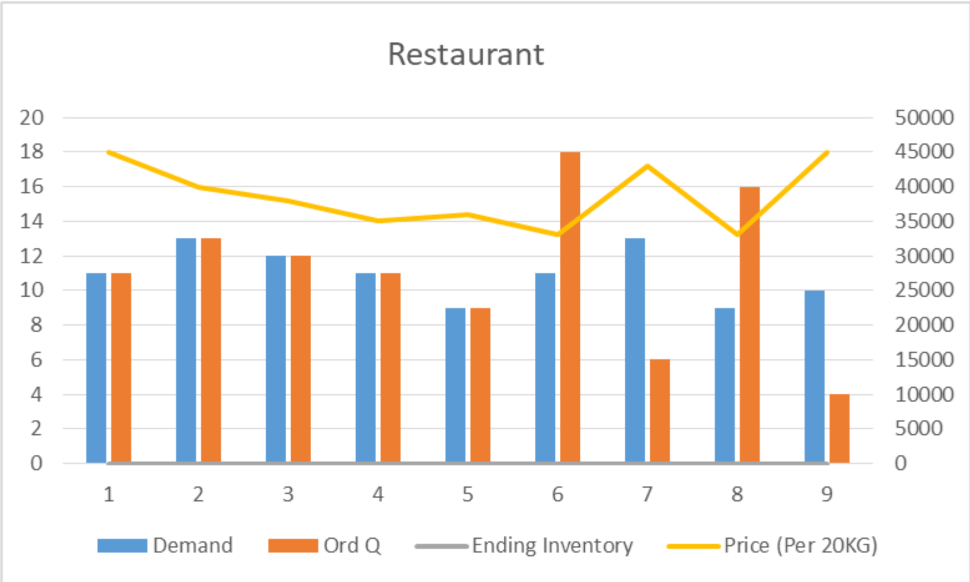
a. Dependent Variable: Price

Table 3: result of regression analysis on the relationship between discrepancy from demand and price.

5.3.4. Proposition 2: Price variability is the cause for distortion in demand information

The direction for proposition 2 is straight forward, price variability is already determined before the retailer's order quantity, Y^r_t, is determined. From the initial price, P^w_t, marked up price , P^r_t, is calculated and informed to the retailers. Based on this price information and their demand from customers, d^r_t, retailer's order quantity, Y_t^r is determined, which cause distortion in demand information. Thus, price variability is the cause for distortion in demand information, but distortion on demand is not the cause for price variability.

Graph 2 highlights the causality of price variability. The restaurant's purchasing strategy was not based on demand but to fulfill their potato inventory to a certain level at the start of the week. As shown on graph 2, their order quantity and demand are matched until week 5. However, when the price of potatoes decreased to a certain level, such as at week 6, they would purchase more than the required inventory level to maximize their profitability, which cause a significant variation in the purchasing quantity.



Graph 2: Weekly Gamjatang Restaurant's demand, order quantity, ending inventory and price (per 20KG) for 9 weeks.

5.3.5. Proposition 3: Demand distortion is the cause the for bullwhip effect

The causality of demand information for the bullwhip effect is proven by various literature. Lee et al (1997b), Shan, J., Yang, S., Yang, S., & Zhang, J. (2014), and Chen, L., & Lee, H. L. (2012) all states that demand information distortion is the key cause for bullwhip effect. Thus, the bullwhip effect is the consequence of demand information distortion, which highlights the causality and the direction of the relationship.

Chapter 6. Results and Discussions

6.1. Proposition 1

Table 3 and 4 contains the result of the Pearson correlation analysis for each two wholesalers, Sookyung Agriculture and Yewon Agriculture. The 4 variables are demand, order quantity, amplification ratio (bullwhip effect), and variance in price. The correlation coefficient for Sookyung Agriculture shows a 0.828 correlation for demand and order quantity with a significant level of 0.01. Also, the results show us that the bullwhip effect (amplification ratio) and price variance have a strong correlation at 0.587 with a 0.05 level of significance. Yewon Agriculture also shows similar results. Yewon Agriculture has a 0.820 correlation coefficient for demand and order quantity with a significant level of 0.01. Also, the bullwhip effect (amplification ratio) and price variance have a strong correlation at 0.578 with a 0.05 level of significance. The relationship between the bullwhip effect and price variance showed a p-value of 0.05 instead of 0.01. This could be assumed that it is because there are other factors that determine the price fluctuation such as supply and competition, instead of only the bullwhip effect and demand. This provides support for our proposition 1; the bullwhip effect has an impact on price variability. Thus, an increase in the bullwhip effect will cause an increase in variation for the initial price. This also provides evidence that the price fluctuation is not only the cause of bullwhip but is also an impact of the bullwhip effect, which was lacking in prior studies.

Sookyung Agriculture Correlations

		Demand	Ord. Q	Bullwhip	Var.Price
Demand	Pearson Correlation	1	.828**	.367	.138
	Sig. (2-tailed)		.000	.179	.624
	N	22	22	22	22
Ord.Q	Pearson Correlation	.828**	1	.077	.105
	Sig. (2-tailed)	.000		.784	.709
	N	22	22	22	22
Bullwhip	Pearson Correlation	.367	.077	1	.587*
	Sig. (2-tailed)	.179	.784		.021
	N	22	22	22	22
Var.Price	Pearson Correlation	.138	.105	.587*	1
	Sig. (2-tailed)	.624	.709	.021	
	N	22	22	22	22

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 3: Result of Pearson Correlation Coefficient Analysis for Wholesaler, Sookyung Agriculture.

Yewon Agriculture Correlations

		Demand	Ord. Q	Bullwhip	Var.Price
Demand	Pearson Correlation	1	.820**	.364	-.202
	Sig. (2-tailed)		.000	.183	.470
	N	22	22	22	22
Ord.Q	Pearson Correlation	.820**	1	.181	-.377
	Sig. (2-tailed)	.000		.519	.166
	N	22	22	22	22
Bullwhip	Pearson Correlation	.364	.181	1	.578*
	Sig. (2-tailed)	.183	.519		.024
	N	22	22	22	22
Var.Price	Pearson Correlation	-.202	-.377	.578*	1
	Sig. (2-tailed)	.470	.166	.024	
	N	22	22	22	22

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 4: Result of Pearson Correlation Coefficient Analysis for Wholesaler, Yewon Agriculture.

6.2. Proposition 2

Table 5 and 6 contains the results of the Pearson correlation analysis for each two retailers, the local supermarket and Gamjatang restaurant. 4 variables are demand, order quantity, distortion of demand (downstream amplification ratio), and variance in price. For the correlation between demand and order quantity, retailers showed different results compared to the wholesalers. Both supermarkets and Gamjatang restaurants showed no significant correlation between demand and order quantity. However, the correlation between distortion of demand (downstream amplification ratio) and price variance was significant. Local supermarkets showed a correlation coefficient of 0.957 with a p-value of 0.01 while Gamjatang restaurant had a correlation coefficient of 0.764 with a p-value of 0.05. This provides support for our proposition 2; price variability has a significant impact on the distortion of demand information for downstream players. Thus, an increase in the fluctuation of the price will increase the distortion of demand information.

As shown in graph 2 and 3, it could be assumed that supermarket (p-value 0.01) has higher significance than restaurants (p-value 0.05) because supermarket can easily change the price on their display to stimulate demand and encourage sales. Thus, supermarket differentiates their order quantity depending on the price of potato every week. Table 5 shows a strong and significant correlation between variance in price and average demand (0.963 with a p-value of 0.001), which further supports this assumption.

The restaurant had an interesting system where they focus on remaining inventory. Their purchasing strategy was not based on demand but to fulfill their potato inventory to a certain level at the start of the week. However, when the price of potatoes decreased to a certain level, they would purchase more than the required inventory level to maximize their profitability, which cause a significant variation in the purchasing quantity. Table 6 shows a strong and significant correlation between variance in price and average ordering quantity (0.879 with a p-value of 0.001), which further supports this assumption.

Super Market Correlations

		Demand	Ord. Q	Bullwhip	Var.Price
Demand	Pearson Correlation	1	-.325	.998**	.963**
	Sig. (2-tailed)		.432	.000	.000
	N	13	13	13	13
Ord.Q	Pearson Correlation	-.325	1	-.382	-.157
	Sig. (2-tailed)	.432		.350	.710
	N	13	13	13	13
Bullwhip	Pearson Correlation	.998**	-.382	1	.957**
	Sig. (2-tailed)	.000	.350		.000
	N	13	13	13	13
Var.Price	Pearson Correlation	.963**	-.157	.957**	1
	Sig. (2-tailed)	.000	.710	.000	
	N	13	13	13	13

**. Correlation is significant at the 0.01 level (2-tailed).

Table 5: Result of Pearson Correlation Coefficient Analysis for retailer, Local Super Market.

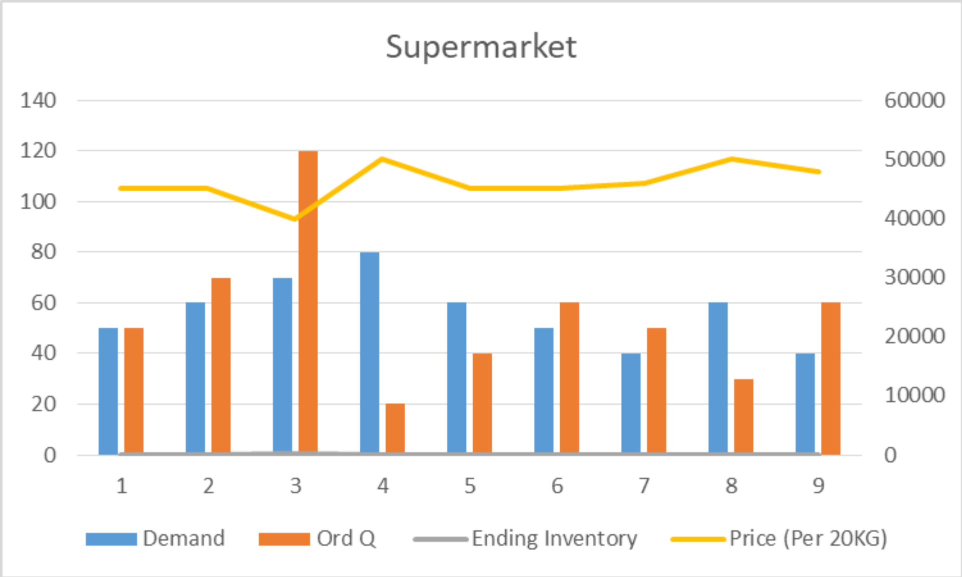
Gamjatang Correlations

		Demand	Ord. Q	Bullwhip	Var.Price
Demand	Pearson Correlation	1	.261	-.260	.299
	Sig. (2-tailed)		.533	.533	.472
	N	13	13	13	13
Ord.Q	Pearson Correlation	.261	1	.699	.879**
	Sig. (2-tailed)	.533		.054	.004
	N	13	13	13	13
Bullwhip	Pearson Correlation	-.260	.699	1	.764*
	Sig. (2-tailed)	.533	.054		.027
	N	13	13	13	13
Var.Price	Pearson Correlation	.299	.879**	.764*	1
	Sig. (2-tailed)	.472	.004	.027	
	N	13	13	13	13

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 6: Result of Pearson Correlation Coefficient Analysis for retailer, Gamjatang Restaurant.



Graph 3: Weekly local supermarket's demand, order quantity, ending inventory and price (per 20KG) for 9 weeks.

6.3. Proposition 3

Summation of all retailer's order quantity ($\sum Y_t^r d_t^w$) represents the wholesaler's demand d_t^w. Thus, an increase in distortion of demand information $BE = \frac{V(Y_t^r)}{V(d_t^r)}$ will obviously increase variation of d_t^w. Therefore only the correlation between retailer's demand and order quantity has to be proven to provide evidence for proposition 3. As stated above, table 3 and 4 show us that there is a strong and significant correlation between demand and order quantity for both retailers at 0.01 level for both companies (0.844 and 0.820). Thus, we can conclude that distortion in demand order quantity will cause further bullwhip effect by increasing demand variability, which will further increase wholesaler order quantity variability, which provides supporting evidence for proposition 3.

Chapter 7. Conclusion and Suggestions

7.1. Conclusion

The key objective of this study is to examine and evaluate the three different relationships; the bullwhip effect and price fluctuation, price fluctuation and demand distortion, and demand distortion and the bullwhip effect. No prior research has integrated price fluctuation into their model to prove how the bullwhip effect impacts price fluctuation.

Figure 9 shows the overall results of the study. The results show that the bullwhip effect has a significant and positive impact on price variability with a correlation coefficient of 0.587 and 0.578 for Sookyung Agriculture and Yewon Agriculture with a p-value of 0.05. This suggests that price, which is determined by supply and demand, is impacted by amplified demand, which is caused by the bullwhip effect. Thus, depending on the level of the bullwhip effect, the level of price fluctuation is determined. Therefore, proposition 1 of the model is supported.

The second proposition, price variability has a significant and positive impact on distortion in demand information, is also supported with a correlation coefficient of 0.957 (p-value of 0.01) and 0.764 (p-value of 0.05) for supermarket and Gamjatang restaurant respectively. This suggests that retailers consider price fluctuation significantly when placing an order. For profit maximization, retailers desire to purchase more produce at a low price level and vice versa. Thus, fluctuation in price will cause retailers to consistently change their ordering quantity and deviate from actual customer demand, which causes significant distortion in demand. This is another evidence that highlights price fluctuation as a cause of the bullwhip effect, which is significantly researched by other studies.

The third proposition, distortion on demand has a significant and positive impact on the bullwhip effect, is supported with a correlation coefficient of 0.844 and 0.820 for Sookyung Agriculture and Yewon Agriculture and a p-value of 0.01. This suggests that wholesalers consider distorted amplified demand as real demand from customers and determine their order quantity based on the distorted information. This is because wholesalers do not have access to real customer demand information. They only receive information from retailers, which is already distorted significantly via price fluctuation (as suggested by proposition 2). Thus, distorted demand information is further amplified, which causes the bullwhip effect. Overall, all 3 proposed relationships between the variables are supported at a significant level. Thus, for the agricultural industry, price fluctuation is not only a causality for the bullwhip effect but is also impacted by the bullwhip effect.

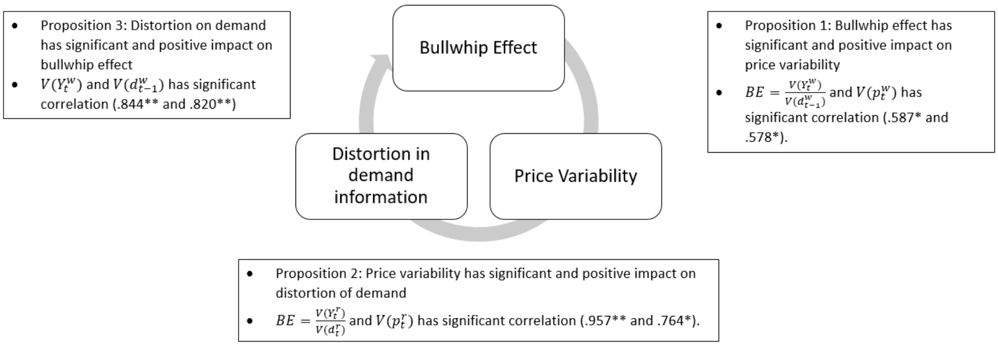


Figure 9: Overall results of the study with correlation coefficient and p-value.

7.2. Academic Contribution

The majority of prior research on the bullwhip effect assumed that price is fixed unless intentionally discounted by promotion or sales. Thus, the impact of the bullwhip effect on pricing was negated when performing their research. However, to highlight the impact of the bullwhip effect on pricing, this study focused on the dynamic pricing industry and included price variability as one of the major variables in the model. The study found that price variability and the bullwhip effect are significantly correlated. The study highlighted how price is impacted by the bullwhip effect and how price impact's bullwhip effect via distorted demand information from downstream players.

There has been significant research on the impact of the bullwhip effect on inventory, back-orders, and efficiency. However, these concepts are most relevant for non-perishable products as they allow inventory and flexibility in capacity. For perishable wholesale industries, one of the major and immediate consequences of a mismatch between supply and actual demand is price fluctuation. In prior studies, price fluctuation was only a cause of the bullwhip effect. However, this study highlights price variation as a consequence of the bullwhip effect that significantly impacts demand variation and information distortion. The study highlights the loop of the bullwhip effect, price variation, and demand distortion, which was never conducted before via empirical means.

As highlighted by Cachon, G. P., Randall, T., & Schmidt, G. M. (2007), the agricultural wholesale industry is ranked second highest in terms of amplification ratio and the bullwhip effect. Perhaps the characteristics of the agricultural supply chain, dynamic pricing, perishability, and inelastic supply, are the factors that cause the bullwhip effect to be more significant via consistent price fluctuation. Hopefully, this study highlights the importance to understand the relationship between the bullwhip effect and pricing and to include an element of price when measuring the impact of the bullwhip effect within a supply chain.

7.3. Managerial Implication

For the agricultural industry, it is important for managers to understand the full impact of the bullwhip effect. Although the bullwhip effect has other consequences such as build-up in inventory and backorder, price is another major factor that managers in the agriculture supply chain must consider. The initial price of their raw produce has a direct impact on the firm's profitability and determines their short and long-term finances and operational strategy. Consistent variation in the price will cause difficulty in their forecasting, marketing, operation, and finance optimization. Thus, firms would not desire constant variation in their cost for their produce. As shown in table 1, the agricultural wholesale industry shows the second-highest amplification ratio. Thus, when considering the bullwhip effect, price variation must be considered to understand the full impact on the agricultural supply chain.

Prior research states that the consequence of the bullwhip effect is more significant to upstream supply chain players such as manufacturers or wholesalers. However, price flow downstream and for the agricultural supply chain, produce and price are transferred immediately because of their characteristics of perishability. Thus, the consequence of price fluctuation impacts downstream supply chain players equally as upstream players. Various studies already state that efforts to reduce the bullwhip effect take time, resources, and investment from all players within the supply chain. However, because the consequence of the bullwhip effect is skewered toward upstream supply chain players, downstream stream players may have been reluctant to participate in the effort. Emphasizing the effect of price fluctuation to downstream players may motivate them to participate in the effort to reduce the bullwhip effect conjointly. Strategy to mitigate the bullwhip effect such as real-time information via blockchain should be considered for the agricultural supply chain. The effort may be costly and time-consuming, but the benefit to the whole supply chain, such as lower market mediation cost, stable pricing, and an increase in overall profitability, will be immense.

Managerial implication is not only limited to the agricultural supply chain but to other industries. Various wholesale industries, such as raw earth materials, semiconductors, and energy utilize dynamic pricing to determine their price. Although prior research stated that the agricultural industry faces one of the highest bullwhip effects, the bullwhip effect is a major problem for other industries as well. Thus, industries that utilize dynamic pricing or industries that fluctuate their initial price consistently must consider if their demand has been significantly amplified by the bullwhip effect. Overall, managers should develop strategies and integrate the supply chain to reduce the bullwhip effect and one of its major consequences; price fluctuation.

7.4. Limitations and future research

The study was only able to obtain two sets of 3-month data for each section of the supply chain. Although 3-month data was verified, more data would have been preferred. The study only focused on one produce (potato) among various different types of agricultural produce. Although potato was one of the most suitable produce to conduct this study, it imposes a restriction on the generalizability of the results of the study. More data from various agricultural produce would be preferred to generalize the model with high certainty. Although there were no supply shocks, the amount of potato that comes into the market is not consistent. The daily quantity of potatoes that comes into the market fluctuates every day. Thus, because supply is another important factor for dynamic pricing, the development of a model that considers variation in supply would be interesting. Although causality and direction have been explained in detail for each proposition, causal analysis that provides quantitative support would be preferred. However, obtaining data and performing experiments in a practical setting would be extremely challenging.

Appendix

Appendix 1

Test of Homogeneity of Variances

		Levene Statistic	df1	df2	Sig.
Price	Based on Mean	9.869	11	60	.000
	Based on Median	8.352	11	60	.000
	Based on Median and with adjusted df	8.352	11	13.805	.000
	Based on trimmed mean	9.690	11	60	.000

ANOVA

Price

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5772481155.833	11	524771014.167	19.171	.000
Within Groups	1642381209.667	60	27373020.161		
Total	7414862365.500	71			

Table 7: Results of F-Test for the annual price of potato (October 2021 ~ September 2022).

Multiple Comparisons

Dependent Variable: Price

Tukey HSD

(I) Month	(J) Month	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
JANUARY	FEBRUARY	-926.66667	3020.65226	1.000	-11197.2061	9343.8728
	MARCH	-2566.66667	3020.65226	.999	-12837.2061	7703.8728
	APRIL	-25264.00000*	3020.65226	.000	-35534.5395	-14993.4605
	MAY	-18247.16667*	3020.65226	.000	-28517.7061	-7976.6272
	JUNE	680.50000	3020.65226	1.000	-9590.0395	10951.0395
	JULY	2117.83333	3020.65226	1.000	-8152.7061	12388.3728

	AUGUST	-1564.50000	3020.65226	1.000	-11835.0395	8706.0395
	SEPTEMBER	-1940.00000	3020.65226	1.000	-12210.5395	8330.5395
	OCTOBER	7641.50000	3020.65226	.342	-2629.0395	17912.0395
	NOVEMBER	4081.16667	3020.65226	.968	-6189.3728	14351.7061
	DECEMBER	765.00000	3020.65226	1.000	-9505.5395	11035.5395
FEBRUARY	JANUARY	926.66667	3020.65226	1.000	-9343.8728	11197.2061
	MARCH	-1640.00000	3020.65226	1.000	-11910.5395	8630.5395
	APRIL	-24337.33333*	3020.65226	.000	-34607.8728	-14066.7939
	MAY	-17320.50000*	3020.65226	.000	-27591.0395	-7049.9605
	JUNE	1607.16667	3020.65226	1.000	-8663.3728	11877.7061
	JULY	3044.50000	3020.65226	.997	-7226.0395	13315.0395
	AUGUST	-637.83333	3020.65226	1.000	-10908.3728	9632.7061
	SEPTEMBER	-1013.33333	3020.65226	1.000	-11283.8728	9257.2061
	OCTOBER	8568.16667	3020.65226	.191	-1702.3728	18838.7061
	NOVEMBER	5007.83333	3020.65226	.880	-5262.7061	15278.3728
	DECEMBER	1691.66667	3020.65226	1.000	-8578.8728	11962.2061
MARCH	JANUARY	2566.66667	3020.65226	.999	-7703.8728	12837.2061
	FEBRUARY	1640.00000	3020.65226	1.000	-8630.5395	11910.5395
	APRIL	-22697.33333*	3020.65226	.000	-32967.8728	-12426.7939
	MAY	-15680.50000*	3020.65226	.000	-25951.0395	-5409.9605
	JUNE	3247.16667	3020.65226	.995	-7023.3728	13517.7061
	JULY	4684.50000	3020.65226	.919	-5586.0395	14955.0395
	AUGUST	1002.16667	3020.65226	1.000	-9268.3728	11272.7061
	SEPTEMBER	626.66667	3020.65226	1.000	-9643.8728	10897.2061
	OCTOBER	10208.16667	3020.65226	.053	-62.3728	20478.7061
	NOVEMBER	6647.83333	3020.65226	.556	-3622.7061	16918.3728
	DECEMBER	3331.66667	3020.65226	.993	-6938.8728	13602.2061
APRIL	JANUARY	25264.00000*	3020.65226	.000	14993.4605	35534.5395
	FEBRUARY	24337.33333*	3020.65226	.000	14066.7939	34607.8728
	MARCH	22697.33333*	3020.65226	.000	12426.7939	32967.8728
	MAY	7016.83333	3020.65226	.473	-3253.7061	17287.3728
	JUNE	25944.50000*	3020.65226	.000	15673.9605	36215.0395
	JULY	27381.83333*	3020.65226	.000	17111.2939	37652.3728
	AUGUST	23699.50000*	3020.65226	.000	13428.9605	33970.0395
	SEPTEMBER	23324.00000*	3020.65226	.000	13053.4605	33594.5395
	OCTOBER	32905.50000*	3020.65226	.000	22634.9605	43176.0395

	NOVEMBER	29345.16667*	3020.65226	.000	19074.6272	39615.7061
	DECEMBER	26029.00000*	3020.65226	.000	15758.4605	36299.5395
MAY	JANUARY	18247.16667*	3020.65226	.000	7976.6272	28517.7061
	FEBRUARY	17320.50000*	3020.65226	.000	7049.9605	27591.0395
	MARCH	15680.50000*	3020.65226	.000	5409.9605	25951.0395
	APRIL	-7016.83333	3020.65226	.473	-17287.3728	3253.7061
	JUNE	18927.66667*	3020.65226	.000	8657.1272	29198.2061
	JULY	20365.00000*	3020.65226	.000	10094.4605	30635.5395
	AUGUST	16682.66667*	3020.65226	.000	6412.1272	26953.2061
	SEPTEMBER	16307.16667*	3020.65226	.000	6036.6272	26577.7061
	OCTOBER	25888.66667*	3020.65226	.000	15618.1272	36159.2061
	NOVEMBER	22328.33333*	3020.65226	.000	12057.7939	32598.8728
	DECEMBER	19012.16667*	3020.65226	.000	8741.6272	29282.7061
JUNE	JANUARY	-680.50000	3020.65226	1.000	-10951.0395	9590.0395
	FEBRUARY	-1607.16667	3020.65226	1.000	-11877.7061	8663.3728
	MARCH	-3247.16667	3020.65226	.995	-13517.7061	7023.3728
	APRIL	-25944.50000*	3020.65226	.000	-36215.0395	-15673.9605
	MAY	-18927.66667*	3020.65226	.000	-29198.2061	-8657.1272
	JULY	1437.33333	3020.65226	1.000	-8833.2061	11707.8728
	AUGUST	-2245.00000	3020.65226	1.000	-12515.5395	8025.5395
	SEPTEMBER	-2620.50000	3020.65226	.999	-12891.0395	7650.0395
	OCTOBER	6961.00000	3020.65226	.485	-3309.5395	17231.5395
	NOVEMBER	3400.66667	3020.65226	.992	-6869.8728	13671.2061
	DECEMBER	84.50000	3020.65226	1.000	-10186.0395	10355.0395
JULY	JANUARY	-2117.83333	3020.65226	1.000	-12388.3728	8152.7061
	FEBRUARY	-3044.50000	3020.65226	.997	-13315.0395	7226.0395
	MARCH	-4684.50000	3020.65226	.919	-14955.0395	5586.0395
	APRIL	-27381.83333*	3020.65226	.000	-37652.3728	-17111.2939
	MAY	-20365.00000*	3020.65226	.000	-30635.5395	-10094.4605
	JUNE	-1437.33333	3020.65226	1.000	-11707.8728	8833.2061
	AUGUST	-3682.33333	3020.65226	.985	-13952.8728	6588.2061
	SEPTEMBER	-4057.83333	3020.65226	.969	-14328.3728	6212.7061
	OCTOBER	5523.66667	3020.65226	.796	-4746.8728	15794.2061
	NOVEMBER	1963.33333	3020.65226	1.000	-8307.2061	12233.8728
	DECEMBER	-1352.83333	3020.65226	1.000	-11623.3728	8917.7061
AUGUST	JANUARY	1564.50000	3020.65226	1.000	-8706.0395	11835.0395

	FEBRUARY	637.83333	3020.65226	1.000	-9632.7061	10908.3728
	MARCH	-1002.16667	3020.65226	1.000	-11272.7061	9268.3728
	APRIL	-23699.50000*	3020.65226	.000	-33970.0395	-13428.9605
	MAY	-16682.66667*	3020.65226	.000	-26953.2061	-6412.1272
	JUNE	2245.00000	3020.65226	1.000	-8025.5395	12515.5395
	JULY	3682.33333	3020.65226	.985	-6588.2061	13952.8728
	SEPTEMBER	-375.50000	3020.65226	1.000	-10646.0395	9895.0395
	OCTOBER	9206.00000	3020.65226	.120	-1064.5395	19476.5395
	NOVEMBER	5645.66667	3020.65226	.773	-4624.8728	15916.2061
	DECEMBER	2329.50000	3020.65226	1.000	-7941.0395	12600.0395
SEPTEMBER	JANUARY	1940.00000	3020.65226	1.000	-8330.5395	12210.5395
	FEBRUARY	1013.33333	3020.65226	1.000	-9257.2061	11283.8728
	MARCH	-626.66667	3020.65226	1.000	-10897.2061	9643.8728
	APRIL	-23324.00000*	3020.65226	.000	-33594.5395	-13053.4605
	MAY	-16307.16667*	3020.65226	.000	-26577.7061	-6036.6272
	JUNE	2620.50000	3020.65226	.999	-7650.0395	12891.0395
	JULY	4057.83333	3020.65226	.969	-6212.7061	14328.3728
	AUGUST	375.50000	3020.65226	1.000	-9895.0395	10646.0395
	OCTOBER	9581.50000	3020.65226	.089	-689.0395	19852.0395
	NOVEMBER	6021.16667	3020.65226	.696	-4249.3728	16291.7061
	DECEMBER	2705.00000	3020.65226	.999	-7565.5395	12975.5395
OCTOBER	JANUARY	-7641.50000	3020.65226	.342	-17912.0395	2629.0395
	FEBRUARY	-8568.16667	3020.65226	.191	-18838.7061	1702.3728
	MARCH	-10208.16667	3020.65226	.053	-20478.7061	62.3728
	APRIL	-32905.50000*	3020.65226	.000	-43176.0395	-22634.9605
	MAY	-25888.66667*	3020.65226	.000	-36159.2061	-15618.1272
	JUNE	-6961.00000	3020.65226	.485	-17231.5395	3309.5395
	JULY	-5523.66667	3020.65226	.796	-15794.2061	4746.8728
	AUGUST	-9206.00000	3020.65226	.120	-19476.5395	1064.5395
	SEPTEMBER	-9581.50000	3020.65226	.089	-19852.0395	689.0395
	NOVEMBER	-3560.33333	3020.65226	.989	-13830.8728	6710.2061
	DECEMBER	-6876.50000	3020.65226	.504	-17147.0395	3394.0395
NOVEMBER	JANUARY	-4081.16667	3020.65226	.968	-14351.7061	6189.3728
	FEBRUARY	-5007.83333	3020.65226	.880	-15278.3728	5262.7061
	MARCH	-6647.83333	3020.65226	.556	-16918.3728	3622.7061
	APRIL	-29345.16667*	3020.65226	.000	-39615.7061	-19074.6272

	MAY	-22328.33333*	3020.65226	.000	-32598.8728	-12057.7939
	JUNE	-3400.66667	3020.65226	.992	-13671.2061	6869.8728
	JULY	-1963.33333	3020.65226	1.000	-12233.8728	8307.2061
	AUGUST	-5645.66667	3020.65226	.773	-15916.2061	4624.8728
	SEPTEMBER	-6021.16667	3020.65226	.696	-16291.7061	4249.3728
	OCTOBER	3560.33333	3020.65226	.989	-6710.2061	13830.8728
	DECEMBER	-3316.16667	3020.65226	.994	-13586.7061	6954.3728
DECEMBER	JANUARY	-765.00000	3020.65226	1.000	-11035.5395	9505.5395
	FEBRUARY	-1691.66667	3020.65226	1.000	-11962.2061	8578.8728
	MARCH	-3331.66667	3020.65226	.993	-13602.2061	6938.8728
	APRIL	-26029.00000*	3020.65226	.000	-36299.5395	-15758.4605
	MAY	-19012.16667*	3020.65226	.000	-29282.7061	-8741.6272
	JUNE	-84.50000	3020.65226	1.000	-10355.0395	10186.0395
	JULY	1352.83333	3020.65226	1.000	-8917.7061	11623.3728
	AUGUST	-2329.50000	3020.65226	1.000	-12600.0395	7941.0395
	SEPTEMBER	-2705.00000	3020.65226	.999	-12975.5395	7565.5395
	OCTOBER	6876.50000	3020.65226	.504	-3394.0395	17147.0395
	NOVEMBER	3316.16667	3020.65226	.994	-6954.3728	13586.7061

*. The mean difference is significant at the 0.05 level.

Price

Tukey HSD[a]

Month	N	Subset for alpha = 0.05	
		1	2
OCTOBER	6	34108.5000	
NOVEMBER	6	37668.8333	
JULY	6	39632.1667	
DECEMBER	6	40985.0000	
JUNE	6	41069.5000	
JANUARY	6	41750.0000	
FEBRUARY	6	42676.6667	
AUGUST	6	43314.5000	
SEPTEMBER	6	43690.0000	
MARCH	6	44316.6667	
MAY	6		59997.1667

APRIL	6		67014.0000
Sig.		.053	.473

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 6.000.

Table 7: Results of Post hoc analysis for the annual price of potato (October 2021 ~ September 2022).

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Abstract

채찍효과(Bullwhip Effect)에 대한 기존 연구의 대부분은 유통기한이 긴 제품(Non-perishable)을 중심으로, 프로모션이나 의도적인 할인이 없는 한 초기 가격이 고정되어 있고, 제품의 공급이 유연하다고 가정합니다. 또한, 채찍효과로 인한 공급망의 증폭된 수요 가변성의 영향은 맥주게임(Beer Game)에서 보다시피 재고 축적(Inventory) 및 이월 주문(Backorder)으로 강조됩니다. 그러나 다양한 산업 분야에서는 재고 축적 및 이월 주문만으로 채찍효과의 영향을 나타낼 수 없습니다. 가격은 수요와 공급에 의해 결정됩니다. 따라서 채찍효과를 통해 증폭된 수요 변동은 가격에 엄청난 영향을 미칠 수 있습니다. 이 연구는 가격을 결정하기 위해 동적 가격 책정 방법을 활용하는 농업 공급망에 채찍 효과가 어떠한 영향을 미치는지에 대하여 초점을 맞춥니다. 또한 농업 공급망의 비탄력적인 공급(Inelastic Supply)과 농산물의 부패 가능성(Perishable)이란 특성 때문에 채찍효과는 농업 가격 결정에 즉각적이고 의미있는 영향을 미칩니다. 이에 본 연구에서는 한국의 대표적인 감자 공급망에서 전개되는 도매경매시스템을 활용한 사례연구를 기반으로 실증연구를 수행하였습니다. 채찍 효과가 가격결정에 영향을 미치고, 이 가격을 기반으로 다운스트림 플레이어들이 수요를 왜곡하고, 다시 채찍 효과를 만들어내는 루프로 영향을 미친다는 것이 본 연구의 결과입니다.

Keyword : 채찍효과, 동적가격책정, 농업 공급망, 부패성, 비탄력적 공급.
Student Number : 2021-20593