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The Relation between Inventory Investment and Price Dynamics in a Distributive Firm*

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Abstract

In this paper, we examine the role of inventory in the price-setting behavior of a distributive firm. Empirically, we show that probability of price change has a positive relation to the scale of the retailer's storage and the frequency of its bargain sales. We also show a negative relation between the frequency of bargain sales and the price elasticity of demand. These results denote that price stickiness varies by the retailers' characteristics. In this paper, we consider that the hidden mechanism of price stickiness comes from the retailer's policy for inventory investment. We develop a partial equilibrium model of the retailer's optimization behavior with inventory and financial restrictions. The results of the numerical experiments suggest that price change frequency depends on the retailer's order cost, storage cost, and menu cost.

Keywords: Inventory; Price Stickiness; Numerical Experiment; (S, s) Policy
JEL Classification: D22, E27, E31

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1. Introduction

1.1. Background

Price stickiness is one of the most important and controversial concepts in macroeconomics. Many macroeconomists consider it as a key concept of the real effect of monetary policy in a macroeconomic model. So far, they have turned to the theory of price dynamics and investigated data to establish empirical facts. This paper studies the mechanism of price stickiness by examining the role of inventory in the price-setting behavior of a distributive firm empirically using micro-data scanned in retail stores, and through numerical experiments of a quantitative model of a distributive firm.

Figure 1 shows the sales prices and quantities sold of a brand of cup noodles in three supermarkets in Japan. We find retailers take different pricing strategies, and their price stickiness, frequency of bargain sales, and sales concentration vary. Figure 1(A) shows that one retailer does not change the price in the window period. However, the quantity sold changes due to demand shocks, and consequently the retailer adopts the strategy of setting the item's price constant. Figure 1(B) shows that another retailer implements bargain sales periodically, during which consumers purchase a significant amount of the bargain item. Figure 1(C) shows that a third retailer very rarely holds bargain sales with large discounts, and most of the items are sold during the bargain sales. From the concentration of quantities sold, we infer the accumulation of the item's inventory not shown in the figure.

In this paper, we attempt to answer three questions: First, what causes the difference in the price-setting strategies among retailers? Second, what is the role of inventory investment in the price-setting behavior of a distributive firm? Finally, how does the business environment affects a retailer's price change probability and bargain sales frequency? To this end, we explore the concept of price dynamics.

1.2. Previous Studies

There are abundant studies in price dynamics using micro price data. The Eurosystem Inflation Persistence Network is a pioneer in this research area; one of its studies was conducted by Fabiani, Loupias, Martins, and Sabbatini (2007). In the US, Cecchetti (1986), Kashyap (1995), Bils and Klenow (2004), and Nakamura and Steinsson (2007) conducted empirical studies on price rigidity. In Japan, Saito and Watanabe (2007), and Matsuoka (2012) conducted empirical research on price dynamics using daily scanner data of retail stores in Japan. Abe and Tonogi (2010) found that there is a variety of pricing strategies among retailers, and that retailers' bargain sale behavior is important in price dynamics. Matsuoka (2012) examined empirically the relationship between monopolistic power and frequency of price change and found a negative relationship between them. In response to these studies, we examines the mechanism that generates price rigidity through inventory holdings with numerical experiments of a quantitative (S, s) model.

There have been several early theoretical studies of inventory investment, which is related to (S, s) policy. In an (S, s) type model, a firm optimally picks some level of inventory, s, below which the firm orders inventory stocks in bunching manner, and increases the stocks to an optimally chsen level, S. Thus S minus s is the optimally lot size of the order. Arrow, Harris, and Marschak (1951) were the first to study (S, s)-type inventory behavior. Arrow, Karlin, and Scarf (1958) also performed seminal work on this type of model. Blinder (1982) examined price stickiness and inventory investment in (S, s)-type models and concluded that "the model helps provide an explanation for sluggish relative prices."[1] This paper adopts the concept of retailer's monopolistic power in retail market and so the firm is able to set his selling price from Blinder's model. Aguirregabiria (1999) also conducted important work in this research field. In his study, he constructed a model of the interaction between price and inventory decisions in retail firms and estimated the model parameters using retail data. He concluded inventory and order costs play important roles in sales promotion behavior.

Recently, several studies on the relation between price stickiness and inventory holding have been performed. That by Kryvtsov and Midrigan (2012) is representative of these studies. Our study is founded on all of these previous studies, and we contribute to the literature with the use of scanner data and numerical experiments.

1.3. Contributions of the Paper

Through this paper, we contribute to the study of price dynamics related to inventory holding in three ways. First, we investigate the empirical relations among a firm's probability of price change, business scale, frequency of bargain sales, and price elasticity of demand using daily scanner data. Second, we focus on the relation between price rigidity and periodic bargain sale behavior, which is often ignored in the macroeconomic context. Third, we construct a numerical model with an (S, s) inventory policy and examine the dynamic nature of price and quantity behavior.

1.4. Organization of the Paper

The rest of this paper is organized as follows. In the next section, we determine the empirical properties for price and quantity of an item (i.e., a popular brand of cup noo-

[1] In page 347, Blinder (1982).

dles) in retailers in Japan. In section 3, we describe the development of the model of a distributive firm with an inventory level that optimizes the sum of the current and discounted future profit in a monopolistic environment. In section 4, we describe the numerical experiments we conducted using the model. We also show the changes in price and bargain sales moments depending on the cost parameters. In section 5, we present the conclusions.

2. Empirical Facts

In this section, we examine daily scanner data collected from retail stores throughout Japan to clarify empirically the relation between pricing behavior and retailers' characteristics.

2.1. Daily Scanner Data

We use Nikkei POS Data from Nikkei Digital Media.[2] Our investigation focuses on a representative item, instant cup noodles, which is a very popular processed food in Japan and whose quality has not changed for a long time. The Nikkei POS Data we examine in this paper covers the period January 1, 2008 to December 31, 2008. We chose this period because it has the most number of stores (235) that sell the item. The data includes quantity sold, price, and number of store visitors. Table 1 shows the pooled summary of statistics for the panel data.

2.2. Moments and Implications

To investigate empirically the relationship between pricing behavior and retailers' characteristics, we compare the moments of the individual stores. Table 2 shows the summary of the moments across stores. Although all the retail stores deal with the same brand of instant cup noodles, their average prices varied from 104 yen to 159 yen. Thus, the standard deviations of the prices varied from 0.2 to 27.9. Similarly, there are significant differences in the probability of price changes and frequency of bargain sales among stores. The price elasticity is estimated by the regression in equation (1):

$$log(p_t^i) = \alpha^i + \beta_1^i \, log(z_t^i) + \beta_2^i \, log(v_t^i) + \epsilon_t^i. \tag{1}$$

p_t^i denotes the price of the item at store *i* in period *t*. z_t^i denotes the quantity sold for the item at store *i* in period *t*. v_t^i denotes the number of visitors to store *i* in period *t*. ϵ_t^i

[2] Nikkei-POS Data are compiled by Nikkei Digital Media Inc. The data set contains daily transaction for a large number of products in various retail shops throughout Japan from March 1, 1988 to thepresent. A more detailed description are in Abe and Tonogi (2010) and Matsuoka (2012).

denotes the residual of the estimation at store i in the period t. β_1^i represents the estimated price elasticity of demand for store i. The price elasticity for demand varies widely, from 5.1 to 471.7. This is because each store faces a different shaped demand function, which indicates each store has a different level of monopolistic power in the market. These facts denote that various pricing strategies are adopted by the retail stores. These facts also raise the question: What causes the difference in pricing strategies?

Figure 3 shows scatter plots of the moments of prices, quantities, and store visitors. Figure 3(A) depicts that probability of price change has little correlation with the average number of visitors (persons/day). In contrast, Figure 3(B) shows that it has a positive correlation with the coefficient of variation for visitors. Since the coefficient of variation for visitors is regarded as the volatility of demand shocks to the item, we consider that the probability of price change is influenced by demand shocks but not by the number of customers or the scale of the retail store.

Meanwhile, Figure 3(C) shows that the probability of price change has no relation to the scale of a retail store and has a moderate positive correlation with the average quantity sold. These findings suggest that the more the retail store sells, the more frequently it changes the price of the item, which in turn suggests that the size or capacity of the retail storage is related to price change probability. Figure 3(D) depicts that volatility of quantity sold has a positive correlation with price change probability. That is, the more frequently a store changes prices, the more volatile its sales. The difference in the flexibility or stickiness of price indicates the difference in the strategy of sales adopted by retail stores.

Figure 3(E) shows an interesting relationship between price change probability and average price. The positive correlation between them implies that price rigidity has a relation to the markup ratio of a retailer. Figure 3(F) shows a positive correlation between the frequency of bargain sales and price change probability. The bargain sales are the important reason for the price changes. Figures 3(G) and 3(F) show that price elasticity of demand has a negative correlation with bargain sales probability and a positive correlation with the discount rate in bargain sales. Especially, it is important to note that a higher price elasticity of demand leads to a lower frequency of bargain sales. Price stickiness comes from the frequency of bargain sales, which is affected by the monopolistic power of a retail store.

The empirical facts regarding the relation between pricing behavior and retailers' characteristics are summarized as follows:

- Probability of price change has a positive relation to the scale or capacity of item storage in a retail store.

- Probability of price change has a negative relation to the average price level of a retail store.
- Price movement in bargain sales is an important cause of price change.
- Frequency of bargain sales has a negative correlation with price elasticity of demand.

In the following section, we investigate these relations in a model of a retail store with an (S, s)-type inventory investment.

3. The Model

We construct a model of a distributive firm that purchases goods in the wholesale market, stocks inventory, and sells this inventory in the retail market. Blinder (1982) investigated the same model in a monopolistic environment. He pointed out that the model explains the sluggish price reaction to cost. Although the model used in this paper is similar to that of Blinder (1982), it also differs from the latter on a few points. First, in our model, we assume a linear cost function because of the assumption that the retailer is a price taker in the wholesale market. Second, we introduce a fixed order cost in order to create an (S, s) policy for inventory investment.[3] Third, we incorporate a stock-out penalty cost, which prompts a store to avoid stock outs, into the model.[4] We construct the model to analyze numerically the relationship between a retailer's price-setting behavior and inventory investment.

3.1. Environment

The empirical facts established in previous section come from an analysis of retail stores' scanner data. In this section, we construct a mathematical model of a retail store's optimal behavior, and then test the model in numerical experiments in the next section.

The model has several differences from the model of a perfect competitive market. First, the distributive firm addresses the demand function of consumers instead of a given price. This assumption is similar to that for Blinder's (1981) model; however, in our model, we do not suppose a linear demand function but a power function, as follows:

[3] Blinder (1981) analyzed the (S, s) policy of inventory investment in detail.
[4] Kahn (1987) constructed the stock-out avoidance model of inventory investment.

$$p_t = a_t x_t^{-\frac{1}{\rho}}, \qquad \rho > 0, \tag{2}$$

where p_t is the price of the item sold in the selling phase in the retail market, x_t is the quantity of the item sold, a_t is the exogenous demand state in the retail market, and ρ is the parameter of price elasticity of demand. Meanwhile, the distributive firm is supposed to be a price taker in the purchasing phase in wholesale market. The firm obtains its operating fund from the profit of its buying and selling operation wherein it purchases the optimal quantity of inventory at an optimal timing In addition, we assume a penalty for stock outs, which would motivate the firm to ensure it has sufficient stock.

When the distributive firm orders inventory in the wholesale market, it incurs a fixed order cost regardless of the quantity it purchased. This order cost gives the firm an incentive to order in bulk instead of purchasing each period. Consequently, an (S, s)-type inventory policy is generated.

We also suppose that the firm faces two other costs: inventory holding cost and menu cost. The inventory holding cost is assumed as a quadratic power function imposed on the inventory stock level held from the previous to the current period. The menu cost is a small cost imposed on changing the selling price. These costs are expected to affect the pricing behavior of the firm. Summing up the distributive firm's environment, the firm's current profit function is expressed as follows:

$$\pi_{\mathrm{t}} = p_t x_t - q_t y_t - c^s s_t^{\phi} - c^x x_t - c^o i_t^o - c^p i_t^p - c^n i_t^n, \tag{3}$$

where q_t is the price of the item purchased in the purchasing phase in the wholesale market, y_t is the quantity of the item purchased, and $\mathrm{s_t}$ is the inventory holding stock. Meanwhile, c^s and ϕ are the cost parameters in the inventory holding cost function; c^x is the operating cost, c^o is the order cost, c^p is the menu cost, and $\mathrm{c^n}$ is the stock-out penalty cost. i_t^o, i_t^p, and i_t^n are indicator functions that take the following values:

$$i_t^o \begin{cases} = 1, & \text{if } y_t > 0 \\ = 0, & \text{if } y_t = 0 \end{cases}, \qquad i_t^p \begin{cases} = 1, & \text{if } p_t \neq p_{t-1} \\ = 0, & \text{if } p_t = p_{t-1} \end{cases}, \qquad i_t^n \begin{cases} = 1, & \text{if } s_t = 0 \\ = 0, & \text{if } s_t > 0 \end{cases}. \tag{4}$$

In addition, the firm is subject to two constraints: cash-in-advance constraint and inventory-in-advance constraint. The cash-in-advance constraint means the firm's purchase amount should not exceed the cash on hand:

$$q_t y_t \leq f_t, \tag{5}$$

The inventory-in-advance constraint means the firm's selling quantity should not exceed the inventory in the storage:

$$x_t \leq s_t, \tag{6}$$

The state variables $\mathrm{s_t}$ and f_t are subject to the following transition equations:

$$s_t = (1-\delta)(s_t - x_t) + y_t, \tag{7}$$

$$f_t = f_t + \pi_t. \tag{8}$$

where δ is the depreciation rate of inventory stock. Both state variables are also subject to non-negativity constraints.

The timeline of the distributive firm activities in period *t* is summarized in Table 3. After the state variables $s_t, f_t,$ and p_{t-1}, which are determined based on the firm's behavior in the previous period, $a_t$and q_t are derived from the data-generating process exogenously, enabling the distributive firm to determine the control variables (x_t, y_t, p_t) optimally.

3.2. Set Up

The problem of the distributive firm is represented as follows:

$$\max_{\mathrm{x_t}, y_t} E\left[\sum_{t=0}^{\infty}\left(\frac{1}{1+r}\right)^t \pi_t | s_t, f_t, p_{t-1}, q_t, a_t\right],$$

$$\begin{aligned}
\text{s.t.}\quad & \pi_t = p_t x_t - q_t y_t - c^s s_t^{\phi} - c^x x_t - c^o i_t^o - c^p i_t^p - c^n i_t^n, \\
& \phi > 0,\ c^s \geq 0,\ c^o \geq 0, c^p \geq 0, c^n \geq 0, \\
& i_t^o \begin{cases} = 1, & \text{if } y_t > 0 \\ = 0, & \text{if } y_t = 0 \end{cases},\ i_t^p \begin{cases} = 1, & \text{if } p_t \neq p_{t-1} \\ = 0, & \text{if } p_t = p_{t-1} \end{cases},\ i_t^n \begin{cases} = 1, & \text{if } s_t = 0 \\ = 0, & \text{if } s_t > 0 \end{cases}, \\
& s_{t+1} = (1-\delta)(s_t - x_t) + y_t,\ s_0 \text{ given}, \\
& f_{t+1} = f_t + \pi_t,\ f_0 \text{ given}, \\
& q_t y_t \leq f_t,\ x_t \leq s_t,\ x_t \geq 0,\ y_t \geq 0,\ s_{t+1} \geq 0,\ f_t \geq 0,
\end{aligned} \tag{9}$$

$$\text{where}\quad \mathrm{p_t} = a_t x_t^{-\frac{1}{\rho}},\ \rho > 0,$$

$$a_t \sim \text{ data generating process}$$

$$q_t \sim \text{ data generating process.}$$

The definitions of the variables and parameters are provided in Table 4. Since the model is non-linear and has many possible binding constraints and indicator functions that are not differentiable, we cannot solve the policy function of the problem by a closed-form analysis, even if we formalize the data generating processes of $\mathrm{a_t}$ and q_t. Thus, we use a numerical method to solve the problem computationally. In concrete terms, we use the method of discrete space dynamic programming with an interpolation method for the value evaluation of the state variables. Our interpolation method is a multi-dimensional linear interpolation method.

3.3. Parameterizations

When we solve the model numerically, it is necessary to specify the concrete functional forms and give values to the parameters. Since the functional forms are already specified in the previous subsection, we calibrate the values of the parameters in this subsection.

First, we parameterize the model of a benchmark case. In the benchmark case, the value of the price elasticity of price ρ is set to 18, which is the median of the estimated values for the elasticity in the previous subsection. The value of the curvature parameter of inventory stock cost, ϕ, is set to 2, indicating the cost function is quadratic. Inventory cost technology, c^s, is set to 0.01. Since we have no a priori information on the inventory holding cost, we have to determine the values of the parameters in the function arbitrarily. The depreciation rate, δ, is set to 0.00. In this paper, the deterioration of products is not considered for simplicity. The discount rate, r, is set to 0.01. This value, however, is too high for making daily decisions, and thus, we adopt the value from the convenience of a value function convergence computation. Although, from the perspective of the manager of a retail store, who moves to another store as part of the personnel changes once every few years, this discount rate is not so high. The values of the order cost, operating cost, menu cost, and stock-out cost are 2.00, 0.05, 0.03, and 5.00 respectively. At present, we have no a priori information about these parameters. To address this issue, we investigate empirically the cost structure of the distributive firm. We summarize the parameterization in Table 5.

4. Numerical Experiments

We solve the parameterized model numerically using the algorithm of a value function iteration on the discrete state space. The state spaces are divided into 20 grids. Therefore, the state variables $s_t, f_t,$ and p_{t-1} each have 20 grids. Likewise, the control variables x_t and y_t each have 20 grids. The values are evaluated in $20 \times 20 \times 20 \times 20 \times 20$

points, and we seek optimal policies from control candidates. We suppose a_t and q_t are constant throughout all periods here, that is, $a_t = 1, \forall t,$ and $q_t = 0.6, \forall t.$

Figure 3 shows the value functions on the state grids of inventory stock and operation fund in the case of $p_{t-1} = 1$. Figures 4 and 5 plot the policy functions for optimal selling quantity and purchasing quantity on their respective grid spaces. The optimal selling quantity in the retail market basically depends on the inventory stock and also somewhat on the operating fund. Likewise, the optimal purchasing quantity in the wholesale market depends mostly on inventory stock. If the retailer experiences a stock out, it has to purchase a significant amount of inventory to replenish its stock. The selling and buying policy function generates the (S, s) behavior of inventory stock.

4.1. Benchmark Case

We demonstrate the deterministic simulation of the distributive firm that is parameterized in the benchmark case in order to understand the behavior of the numerical model. Figures 6 and 7 plot the simulated paths of the variables in the window, which focuses on the last 50 periods of the 20,000-period simulation. Figure 6 shows the periodic bargain sales in an environment without selling price fluctuations and demand state fluctuations. Figure 6 resembles the actual retail store's behavior presented in Figure 1(C). The firm purchases inventory stock in the wholesale market once every seven periods in order to save on order cost. The firm also holds bargain sales in the retail market in the period after purchasing inventory in order to save on inventory stock cost. After the bargain sales, the firm hikes up the price in the retail market and then fixes the price for six periods in order to save on menu cost. Figure 7 shows the firm's (S, s) behavior of inventory and similar reversal movements of the operating fund.

After purchasing inventory in bulk, the firm accumulates the operating fund required to purchase inventory next time. We perform deterministic simulations of the model, assigning various values to the cost and demand function parameters. Table 6 summarizes the moments of price dynamics and bargain sale behavior. The bargain sale frequency is calculated as follows: we indicate 1 when the difference between the mode price and sold price is more than 2 and indicate 0 otherwise. The average of these scores is the frequency of bargain sales. The price change frequency is calculated as follows: we indicate 1 when $\mathrm{p}_{t-1} \neq p_t$ and indicate 0 otherwise. The average of these scores is the frequency of price change.

4.2. Menu Cost

The menu cost affects the price-setting and bargain sale behaviors. A higher menu cost leads to a lower probability of price change and a lower frequency of bargain sales. On the other hand, a higher menu cost leads to a higher average change rate of price. Figure 8 shows that a higher menu cost prompts the distributive firm to prolong the interval between bargain sales.

4.3. Storage Cost

Storage cost plays an important role in the cyclical bargain sale behavior. Figure 9 shows the selling price movements in the various storage cost parameters. If the storage cost is set to zero, the firm sets a low price every day without holding bargain sales (Figure 9 (A)). If the cost of storage increases, the firm has an incentive to implement bargain sales immediately after it purchases inventory in order to save on storage cost (Figures 9(B), (C)). Without the storage cost, the firm purchases inventory in a large quantity at once, and then sets a low price and sells greater quantities than in the benchmark case. If the storage cost increases even further, the firm is prompted to sell more of the inventory than usual not only for the period after purchasing the inventory but for several periods after that (Figure 9(D)).

4.4. Order Cost

The interval between bargain sales is directly affected by the order cost. Figure 10(A) shows that the firm has no incentive to hold bargain sales in the case of a low order cost ($c^o = 1$). Because of the low order cost, the firm purchases inventory not in bulk but in a constant quantity every period. Thus, the firm's inventory stock level and selling quantity are always constant. When the firm implements bargain sales frequently, it incurs a higher order cost. To save on order cost, the firm thus holds bargain sales less frequently (Figures 10(B), (C), and (D)). The probability of price changes is zero in the case that the order cost is set to 1, but the higher order cost leads to a lower probability of price changes in the case that the order cost is set to above 1.5 (Table 6).

4.5. Price Elasticity of Demand

The price elasticity of demand affects the price dispersion, as indicated in measures such as the standard deviation, max-min difference, average change rate, and average discount rate (Figure 11). The higher elasticity leads to a lower average discount rate and average change rate of price (Table 6). Meanwhile, the price elasticity of demand does not affect the frequency of bargain sales and price change. Because the empirical analysis described in section 2 shows a negative correlation between the price elasticity of demand and the frequency of bargain sales, the numerical experiments discussed here cannot explain the relation between the frequency of bargain sales and price change. More studies are needed to elucidate the relation.

4.6. Discussion

In this subsection, we compare and examine the results of the empirical analysis in section 2 and the numerical experiments on the model of a distributive firm.

First, the empirical results indicate that the probability of price change has positive relation to the quantity sold in a retail store. They imply that the higher quantity sold leads to a higher probability of price change related to the inventory storage cost. The retailer, which has a large capacity but a low marginal cost for storing inventory, purchases inventory frequently and sells much of it every period without much account for the menu cost. Therefore, the positive relation between average quantity and probability of price change may come from the inventory holding cost structure.

Second, the empirical results also suggest that the probability of price change has negative correlation with the average price level. Likewise, the experimental results indicate that a rise in the menu cost leads to an increase in the average price level and a decrease in the frequency of price changes. We find the same relationship when the order cost arises over 0.01. Thus, the negative correlation between probability of price changes and average price level may be explained by the retailer's menu cost and order cost.

Third, the empirical results also indicate that an important source of price change is price movement in the retailer's bargain sale behavior. Since the demand shocks and the purchasing price shocks are ignored in our experiments, the price changes are related to the bargain sale behavior immediately after purchasing inventory in the wholesale market. Further research on the model of a distributive firm with demand and purchasing price shocks are needed in order to investigate on the lag of timing between bargain sale and purchasing inventory.

Finally, the empirical results also show that the frequency of bargain sales has a negative correlation with the price elasticity for demand. We cannot replicate the relationship between the two in the experiments about the various values of the price elasticity for demand. In the real world, the retail store having the stronger monopolistic power in its retail market may be subjected to the higher order cost. Further empirical research is needed on this point.

5. Conclusion

This paper examines the role of inventory in the price-setting behavior of a distributive firm. Empirically, this paper shows that probability of price change has a positive relation to the scale of the retailer's storage and frequency of its bargain sales. Our data analysis also shows a negative correlation between the frequency of bargain sales and the price elasticity of demand. These findings denote that price stickiness varies depending on the characteristics of a retailer.

The paper considers that the hidden mechanism of price stickiness comes from retailer's policy for inventory investment. We develop a partial equilibrium model of a retailer's optimization behavior with inventory and financial restrictions. The numerical experiments suggest that price change frequency depends on a retailer's order cost, storage cost, and menu cost. Our main findings are as follows. First, a higher menu cost leads to a lower probability of price change and a lower frequency of bargain sales. On the other hand, a higher menu cost leads to a higher average change rate of prices and keeps prices from changing within a shorter period. The second, if the storage cost is set to zero, the firm sets a low price every day without holding bargain sales.

Third, if the cost of storage increases, the firm has an incentive to hold a bargain sale immediately after it purchases inventory in order to save on storage cost. Fourth, the firm has no incentive to hold a bargain sale when the order cost is relatively low. Fifth, when the firm holds bargain sales frequently, it incurs high order costs. To save on order cost, it thus holds bargain sales less frequently. Finally, the price elasticity of demand does not affect the frequency of bargain sales and price change.

References

- Abe, N. and A. Tonogi, 2010. "Micro and Macro Price Dynamics in Daily Data," *Journal of Monetary Economics*, 57(6), 716-728.
- Aguirregabiria, V., 1999. "The Dynamics of Markups and Inventories in Retailing Firms," *The Review of Economic Studies*, 66(2), 275-308.
- Arrow, K. J., T. Harris, and J. Marschak, 1951. "Optimal Inventory Policy," *Econometrica*, 19(3), 250-272.
- Arrow, K. J., S. Karlin, and H. Scarf, 1958. *Studies in Mathematical Theory of Inventory and Production*, Stanford University Press.
- Bils, M. and P. J. Klenow, 2004. "Some Evidence on the Importance of Sticky Prices," *Journal of Political Economy*, 112(5), 947-985.
- Blinder, A. S., 1981. "Retail Inventory Behavior and Business Fluctuations," *Brookings Papers on Economic Activity*, 12(2), 443-520.
- Blinder, A. S., 1982. "Inventories and Sticky Prices: More on the Microfoundations of Macroeconomics," *American Economic Review*, 72(3), 334-348.
- Cecchetti, S. G., 1986. "The Frequency of Price Adjustment: A Study of the Newsstand Prices of Magazines," *Journal of Econometrics* 31(3), 255-274.
- Fabiani, S., C. Loupias, F. Martins, and R. Sabbatini, 2007. *Pricing Decisions in the Euro Area: How Firms Set Prices and Why*, Oxford University Press.
- Kahn, J. A. 1987. "Inventories and the Volatility of Production," *The American Economic Review*, 77(4), 667-679.
- Kashyap, A. K., 1995. "Sticky Prices: New Evidence from Retail Catalogs," *Quarterly Journal of Economics*, 110(1), 245-274.
- Kryvtsov, O. and V. Midrigan, 2012. "Inventories, Markups, and Real Rigidities in Menu Cost Models," *The Review of Economic Studies*, 80(1), 249-276.
- Matsuoka, T., "Price Rigidity and Market Structure: Evidence from the Japanese Scanner Data," Research Center for Price Dynamics Working Paper Series, 4.
- Nakamura, E. and J. Steinsson, 2007. "Five Facts about Prices: A Reevaluation of Menu Cost Model," *Quarterly Journal of Economics*, 123(4), 1415-1464.
- Saito, Y. and T. Watanabe, 2007. "Menu Costs and Price Change Distributions: Evidence from Japanese Scanner Data," *Research Center for Price Dynamics Working Paper Series*, 17.

Tables and Figures

Figure 1: Price Setting and Quantity Sold in Retailers

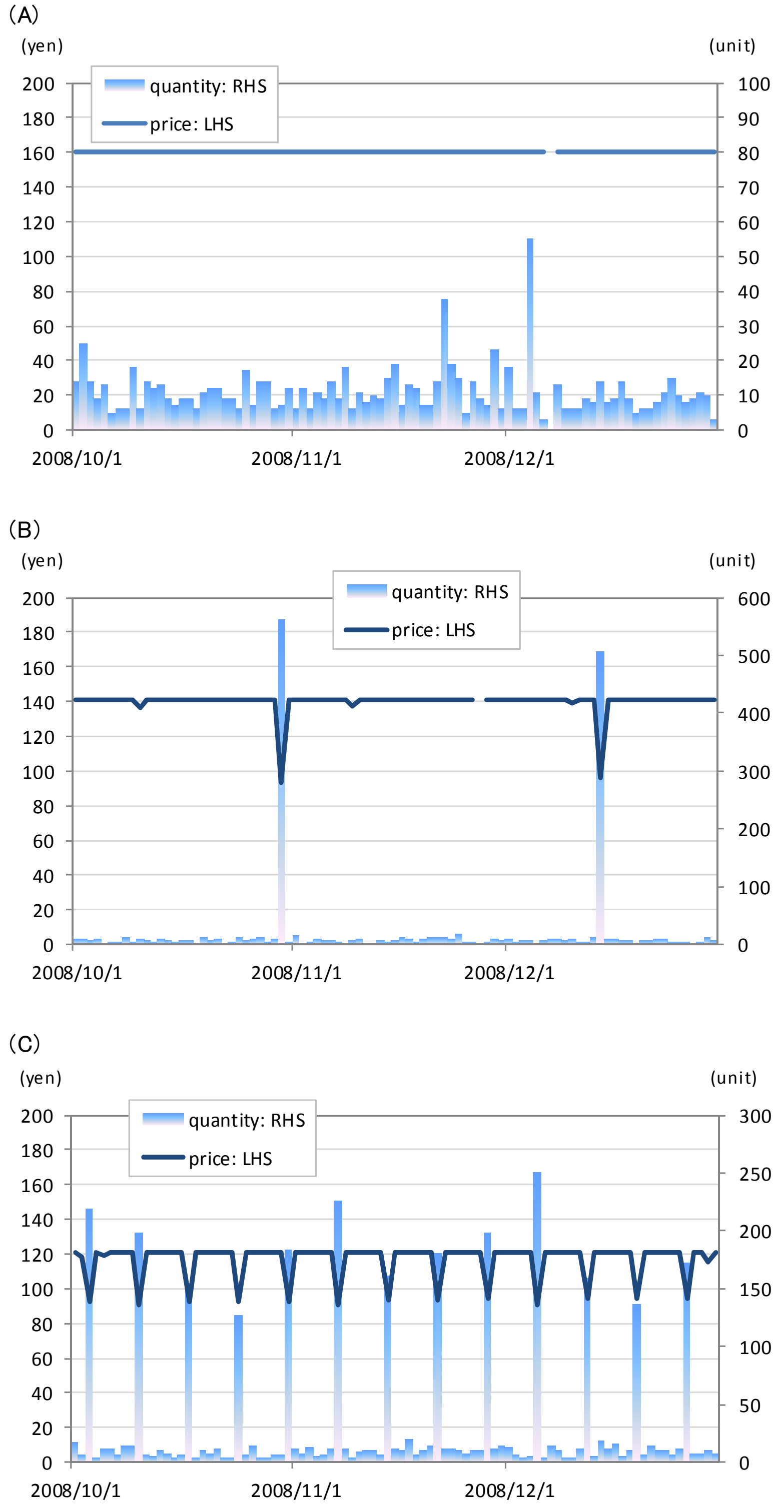


Table 1: Summary of Statistics for Pooled Data

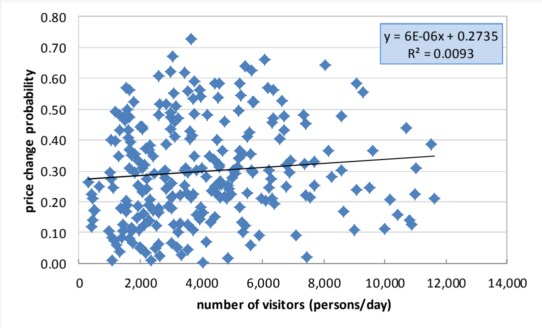
Variable	Obs	Mean	Std. Dev.	Min	Max
storecode	92,598	609.0	379.9	1	1152
date	92,598	-	105.7	2008/1/1	2008/12/31
quantity	85,207	20.8	49.0	1	3,529
price	85,207	128.7	16.3	16	178
visitor	92,163	4,064.8	2,748.7	169	29,149

Table 2: Summary of Moments for Retail Stores

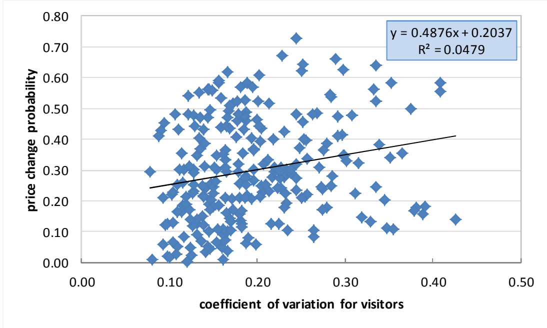
Within Moment	Obs	Mean	Std. Dev.	Min	Max
# of Days	253	364	2	344	366
Visitors/ day	253	4,062	2,499	300	11,608
Coefficient of Variance (Visitors/Day)	253	0.196	0.074	0.077	0.426
Average Price	253	129.421	11.436	103.922	159.266
Mode Price	253	133.269	13.800	110.000	160.000
Median Price	253	133.269	13.800	110.000	160.000
Standard Deviation of Price Level	253	11.475	4.130	0.194	27.874
Skewness of Price	253	-1.108	1.406	-7.858	2.541
Kurtosis of Price	253	6.957	10.402	1.250	104.189
Probability of Price Changes	253	0.299	0.164	0.003	0.726
Average Rate of Price Changes	253	0.273	0.669	-0.358	7.522
Standard Deviation of Price Change Rate	253	5.857	5.569	0.076	64.085
Probability of Bargain Sales	253	0.283	0.150	0.000	0.662
Average Discount Rate	252	-14.455	5.584	-31.685	-3.770
Standard Deviation of Discount Rate	252	6.439	2.999	0.000	20.006
Sales Quantity/Day	253	20	16	2	89
Sales Amount/Day	253	2,270	1,749	202	9,853
Coefficient of Variance (Sales Quantity/Day)	253	1.72	0.95	0.53	5.72
Coefficient of Variance (Sales Amount/Day)	253	1.48	0.71	0.53	4.24
Price Elasticity of Demand	252	27.00	40.75	5.10	471.70

Figure 2: Relations among Moments

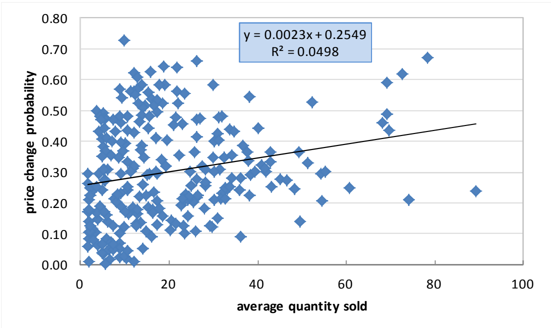
(A) Price Change Probability and Average Visitors



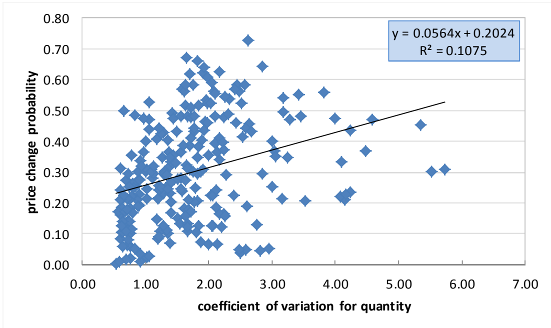
(B) Price Change Probability and Volatility of Visitors



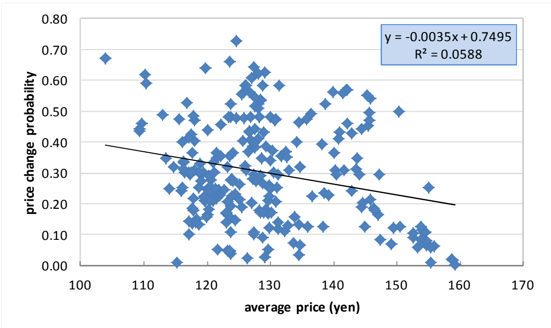
(C) Price Change Probability and Average Quantity



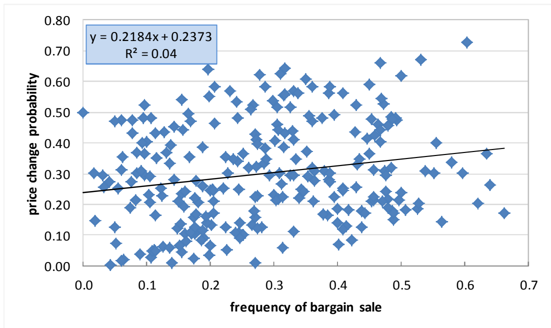
(D) Price Change Probability and Volatility of Quantity



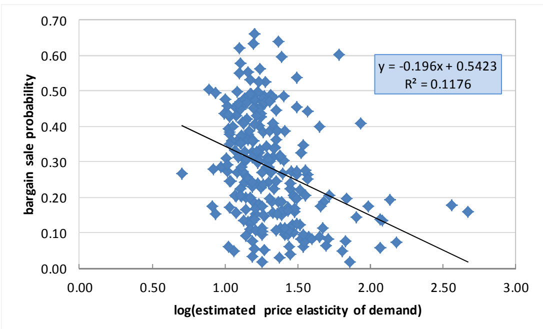
(E) Price Change Probability and Average Price



(F) Price Change Probability and Frequency of Bargain Sales



(G) Frequency of Bargain Sales and Price Elasticity of Demand



(H) Discount Rate and Price Elasticity of Demand

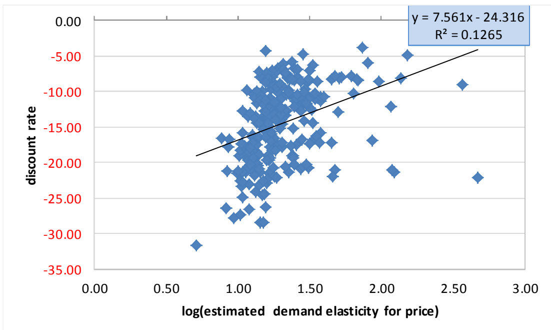


Table 3: Time Line of a Distributive Firm's Decision

period	session	activity		indicator function
t-1		Endogenous	Exogenous	
t	state variables (t)	s(t) f(t) p(t-1)	a(t) q(t)	
	selling time	selling goods in retatil market: p(t)x(t) s.t. x(t)≦s(t) (selling ceiling) p(t)=D[x(t)] (demand function) x(t)≧0		if p(t)≠p(t-1) then i_p(t)=1 otherwise i_p(t)=0
	purchasing time	purchasing goods in wholesale market: q(t)y(t) s.t. q(t)y(t)≦f(t) if f(t)<0 then y(t)=0 y(t)≧0		if y(t)>0 then i_o(t)=1 otherwise i_o(t)=0
	settlement time	profit function π(t)=p(t)x(t)-q(t)y(t)-c_x*x(t)-c_s(s(t))^ϕ -c_o*i_o(t)-c_p*i_p(t)-c_n(t)*i_n(t) calculating state variables of next period s(t+1)=s(t)-x(t)+y(t) f(t+1)=f(t)+π(t)		if s(t)=0 then i_s(t)=1 otherwise i_s(t)=0
		Endogenous	Exogenous	
t+1	state variables (t+1)	s(t+1) f(t+1) p(t)	a(t+1) q(t+1)	

Table 4: Definitions of Variables and Parameters

Variables		Parameters	
p_t	Selling price	ρ	Price elasticity of demand
x_t	Selling quantity	ϕ	Curvature of inventory cost
a_t	Demand state	δ	Depreciation rate of inventory
q_t	Purchasing price	r	Discount rate
y_t	Purchasing quantity	c^s	Inventory cost technology
s_t	Inventory stock	c^o	Order cost
f_t	Operating fund	c^x	Operating cost
i_t^o	Indicator of order	c^n	Stock-out cost
i_t^p	Indicator of price change		
i_t^n	Indicator of stock-out		
π_t	Current profit		

Table 5: Parameterization in a Basic Case

Parameters		Value
ρ	Price elasticity of demand	18.0
ϕ	Curvature of inventory cost	2.00
δ	Depreciation rate of inventory	0.00
r	Discount rate	0.01
c^s	Inventory cost technology	0.01
c^o	Order cost	2.00
c^x	Operating cost	0.05
c^n	Stock-out cost	5.00
c^p	Menu cost	0.03

Figure 3: Value Function on the Grid of $\mathbf{p_{t-1} = 1}$

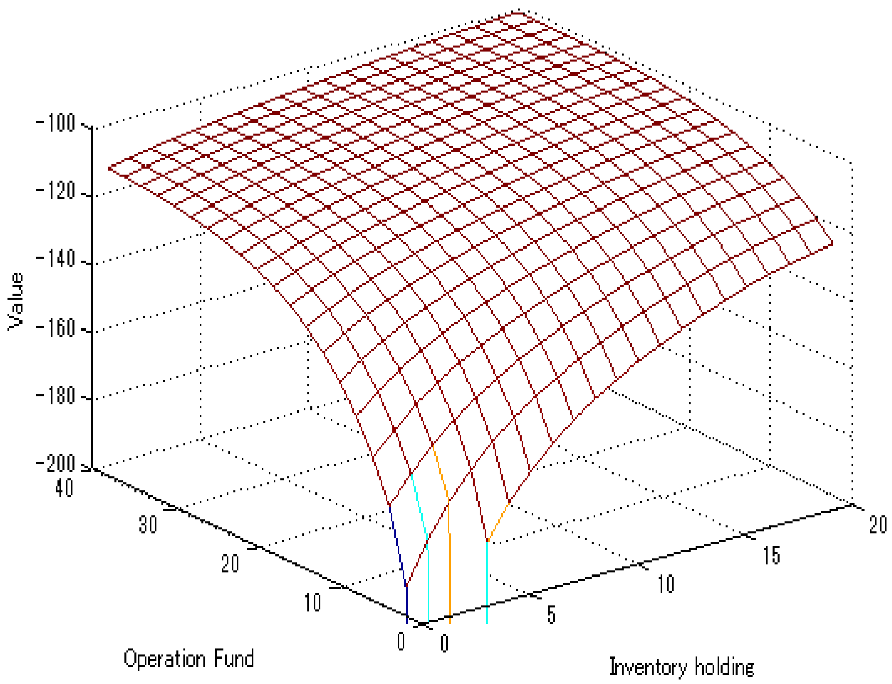


Figure 4: Policy Function of Selling Quantity on the Grid of $p_{t-1} = 1$

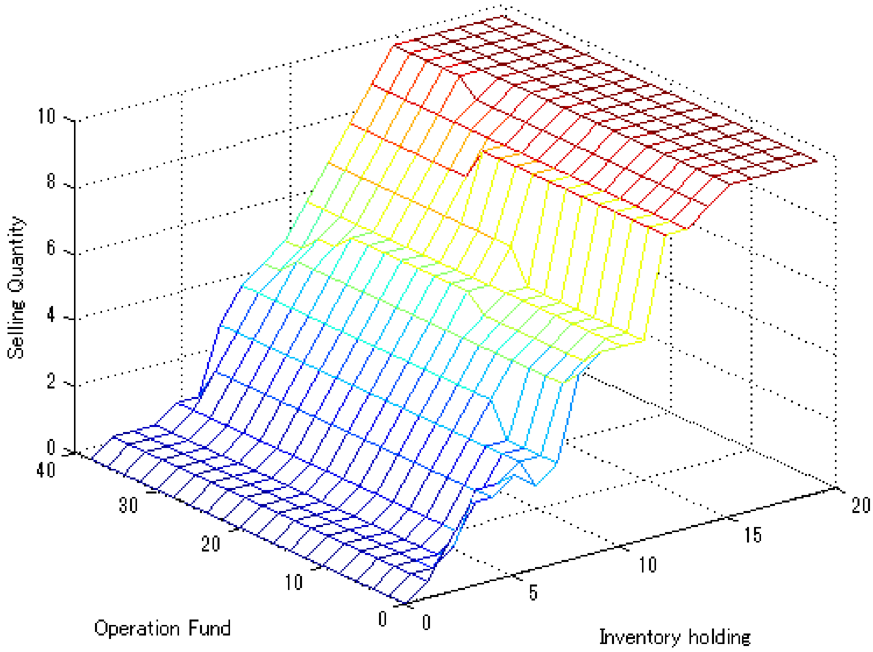


Figure 5: Policy Function of Purchasing Quantity on the Grid of $p_{t-1} = 1$

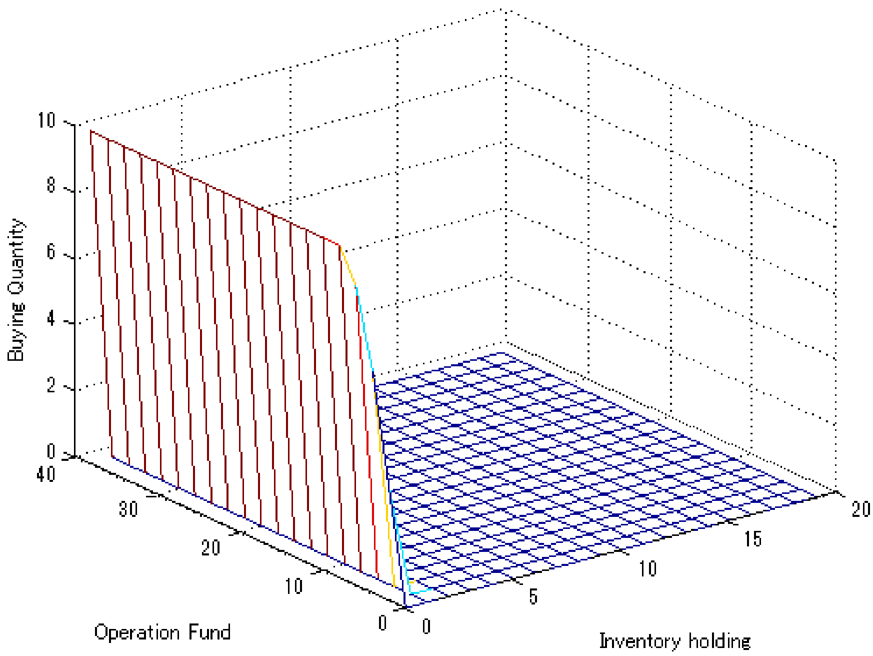


Figure 6: Deterministic Simulation in a Benchmark Case: Price and Quantity

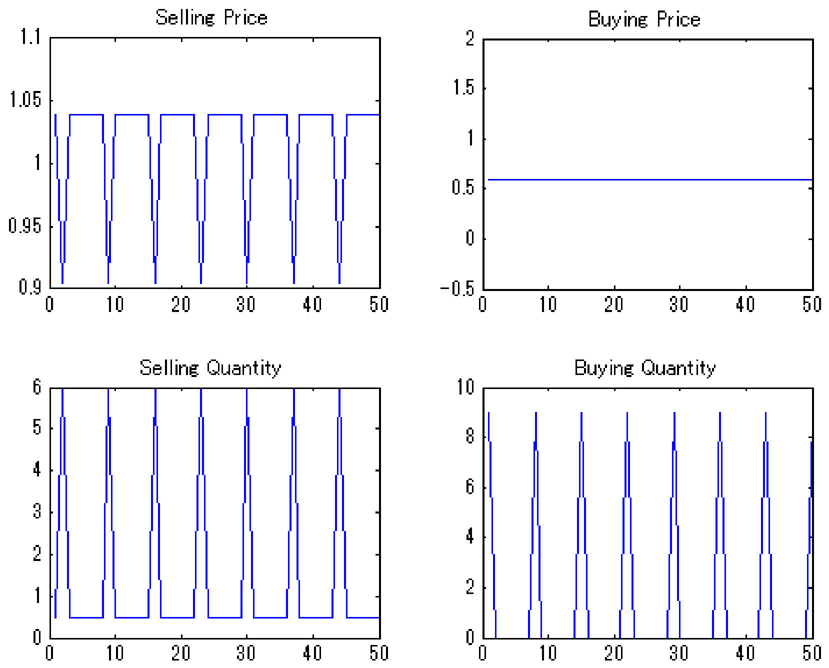


Figure 7: Deterministic Simulation in a Benchmark Case: State and Profit

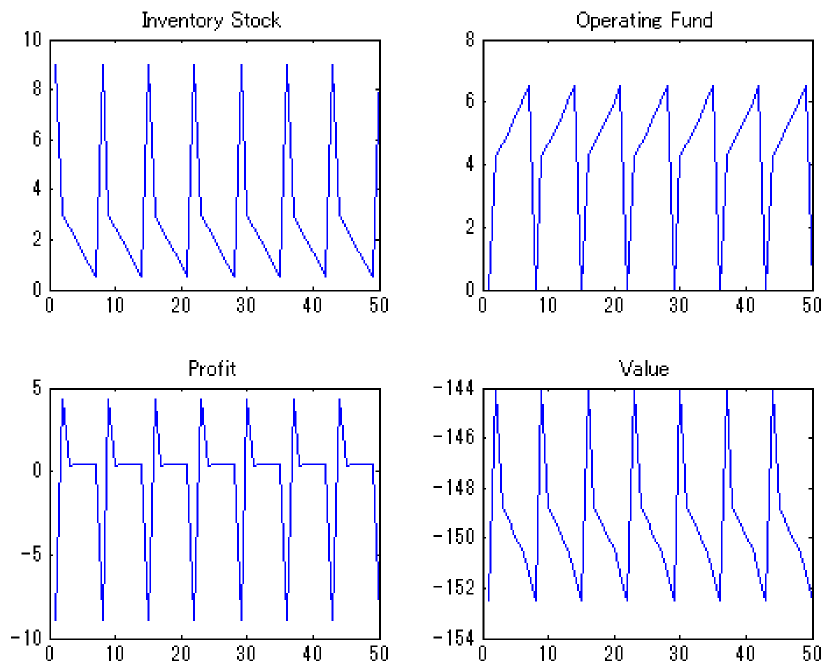


Table 6: Moments for Price Dynamics and Distributive Firm Characteristics

elasticity of demand	order cost	storing cost	menu cost	selling price					selling quantity					price change		bargain sale	
ρ	c^o	c^s	c^p	average	SD	max	min	mode	average	SD	max	min	mode	frequency	average rate	frequency	average rate of discount
			0.00	1.00	0.05	1.04	0.91	1.04	1.67	2.01	6.00	0.50	0.50	0.50	9.20	0.33	10.75
			0.01	1.01	0.05	1.04	0.91	1.04	1.43	1.88	6.00	0.50	0.50	0.43	9.21	0.43	7.17
18	2.00	0.010	0.03	1.02	0.05	1.04	0.91	1.04	1.28	1.92	6.00	0.50	0.50	0.29	13.81	0.14	13.81
			0.06	1.02	0.05	1.04	0.91	1.04	1.28	1.92	6.00	0.50	0.50	0.29	13.81	0.14	13.81
			0.10	1.02	0.04	1.04	0.91	1.04	1.11	1.73	6.00	0.50	0.50	0.22	13.81	0.11	13.81
		0.000		0.88	0.00	0.89	0.88	0.89	9.50	0.50	10.00	9.00	10.00	0.50	0.59	0.00	NaN
		0.005		0.92	0.03	0.94	0.88	0.94	5.33	3.30	10.00	3.00	3.00	0.67	6.69	0.33	6.69
18	2.00	0.010	0.03	1.02	0.05	1.04	0.91	1.04	1.28	1.92	6.00	0.50	0.50	0.29	13.81	0.14	13.81
		0.015		1.02	0.05	1.04	0.91	1.04	1.28	1.92	6.00	0.50	0.50	0.29	13.81	0.14	13.81
		0.020		1.01	0.05	1.04	0.91	1.04	1.33	1.65	5.00	0.50	0.50	0.50	8.53	0.33	8.33
	1.00			0.89	0.00	0.89	0.89	0.89	9.00	0.00	9.00	9.00	9.00	0.00	NaN	0.00	NaN
	1.50			1.00	0.05	1.04	0.90	1.04	2.00	2.51	7.00	0.50	1.00	0.60	9.77	0.60	7.45
18	2.00	0.010	0.03	1.02	0.05	1.04	0.91	1.04	1.28	1.92	6.00	0.50	0.50	0.29	13.81	0.14	13.81
	2.50			1.02	0.04	1.04	0.91	1.04	1.11	1.73	6.00	0.50	0.50	0.22	13.81	0.11	13.81
	3.00			1.02	0.04	1.04	0.91	1.04	1.11	1.73	6.00	0.50	0.50	0.22	13.81	0.11	13.81
14				1.03	0.06	1.05	0.88	1.05	1.29	1.93	6.00	0.50	0.50	0.29	17.75	0.14	17.75
18	2.00	0.010	0.03	1.02	0.05	1.04	0.91	1.04	1.28	1.92	6.00	0.50	0.50	0.29	13.81	0.14	13.81
26				1.01	0.04	1.03	0.92	1.03	1.57	2.62	8.00	0.50	0.50	0.29	10.66	0.14	10.66

Note: The bargain sale frequency is calculated as follows: we indicate 1 when the difference between mode price and sold price is more than 2 and indicate 0 otherwise. The average of these scores is the frequency of bargain sales. The price change frequency is calculated as follows: we indicate 1 when p_(t-1) ≠p_t and indicate 0 otherwise. The average of these scores is the frequency of price changes.

Figure 8: Simulation Results for Pricing and Menu Cost

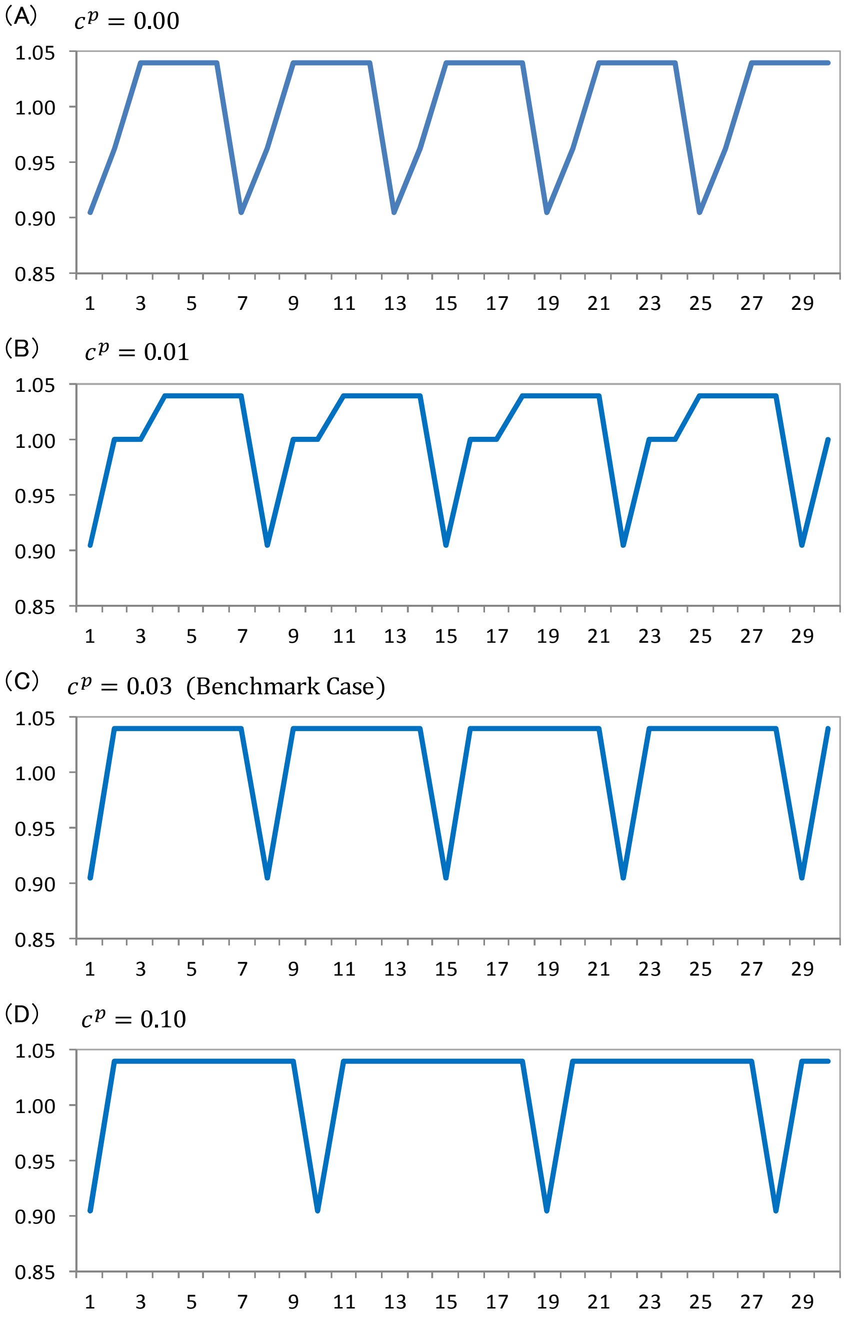
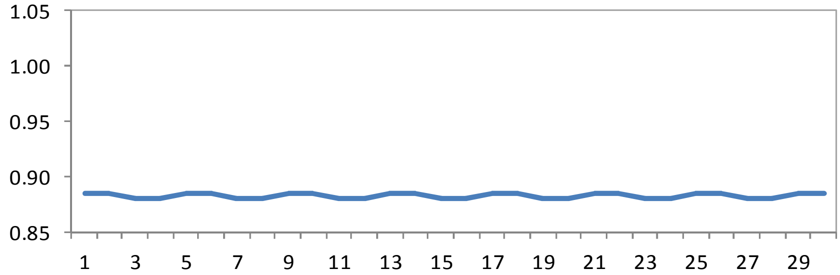
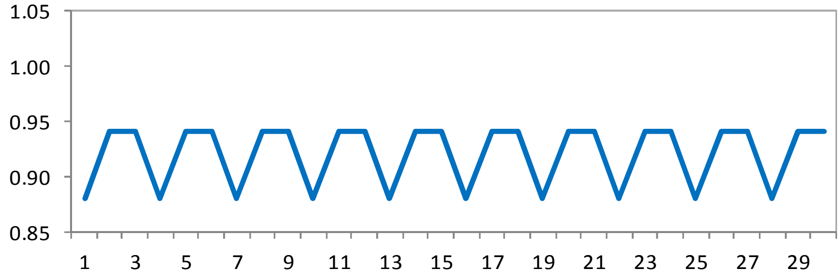


Figure 9: Simulation Results for Pricing and Storage Cost

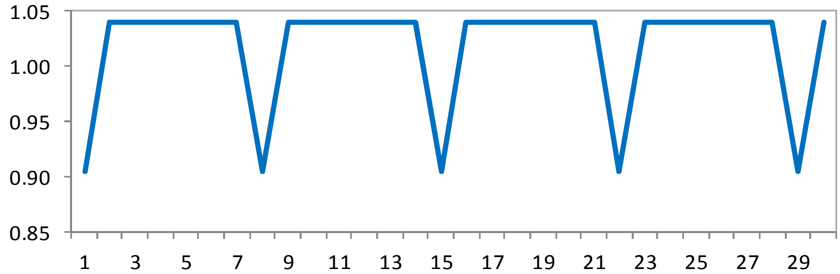
（A）　$c^s = 0.00$



（B）　$c^s = 0.005$



（C）　$c^s = 0.010$（Benchmark Case）



（D）　$c^s = 0.020$

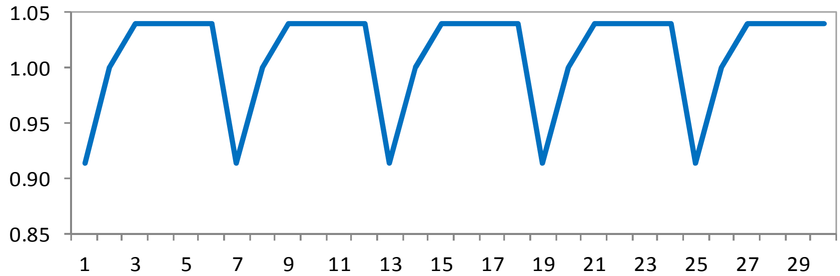


Figure 10: Simulation Results for Pricing and Order Cost

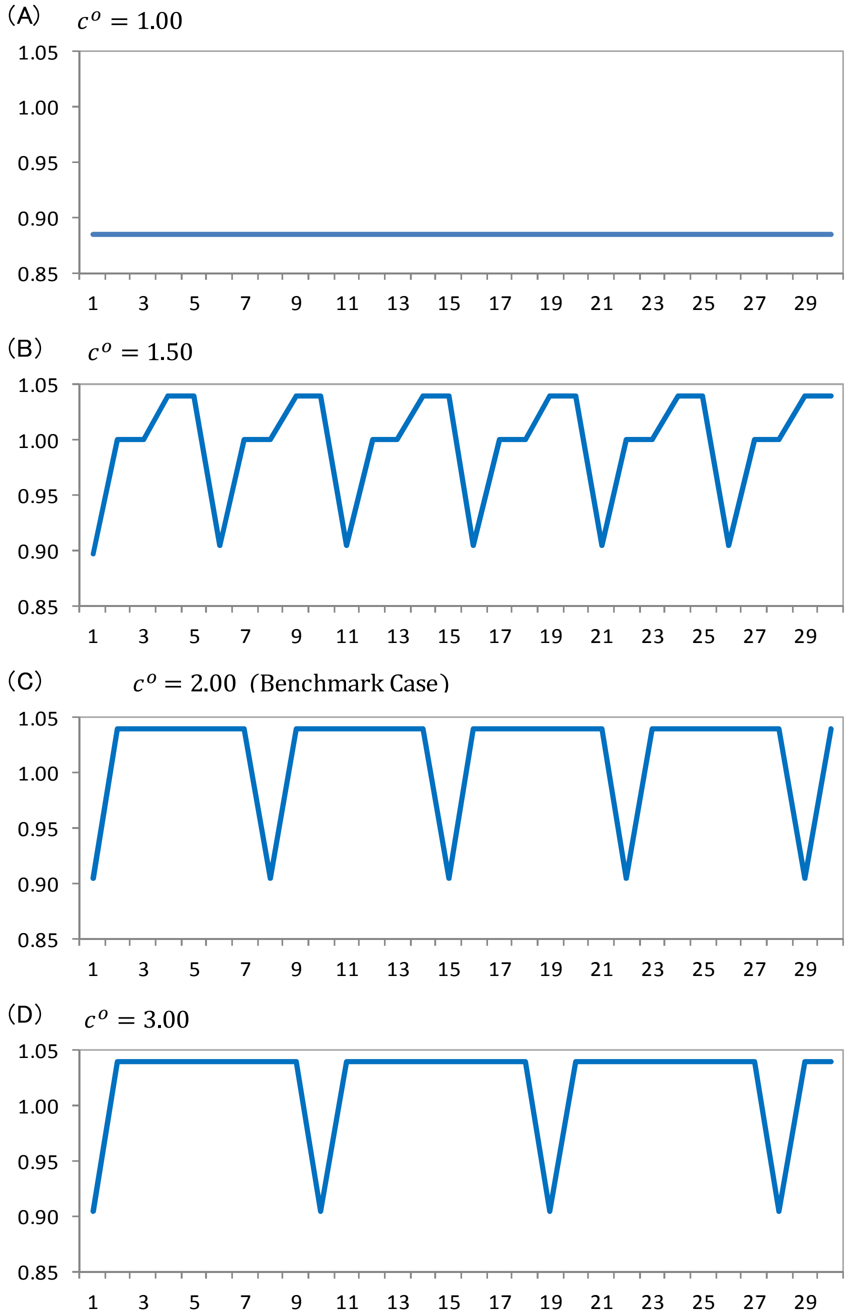
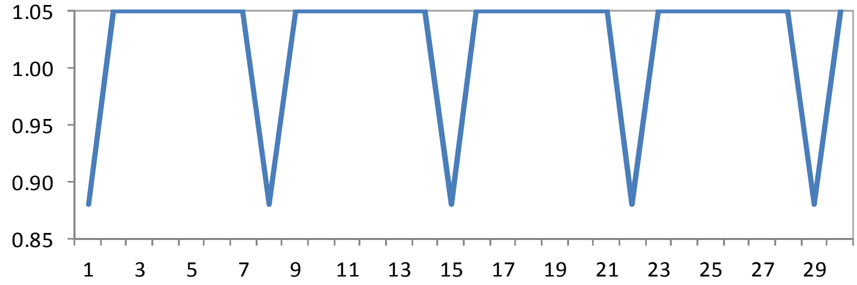
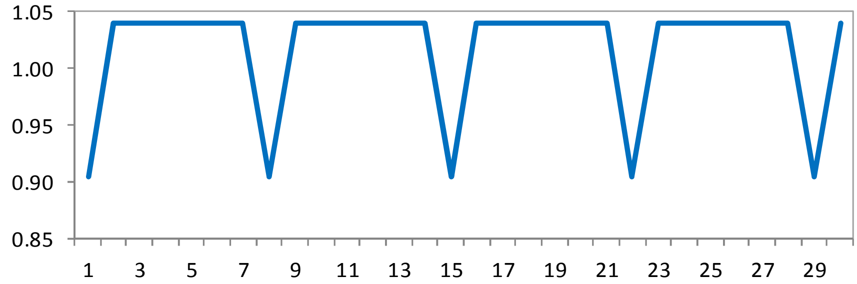


Figure 11: Simulation Results for Pricing and Price Elasticity of Demand

(A) $\rho = 14$



(B) $\rho = 18$ (Benchmark Case)



(C) $\rho = 26$