



## Forecasting global adoption of crystal display televisions with modified product diffusion model

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### ABSTRACT

Liquid crystal display televisions (LCD TVs) embody properties of durable and high-technological products. In this work, we relax the restrictive assumptions of constant internal influence in the conventional growth model for worldwide diffusion of LCD TV innovation. Based upon the price impact on the imitating behaviors, we incorporate price factor into the Bass model to study evolutions of LCD TV market. Effects of innovation, imitation, price elasticity and potential market factors are systematically considered. Two different models, the conventional Bass model and the modified one are thus numerically solved and optimized to estimate the market dynamics of LCD TVs, where the results among the models as well as the collected data in the past decade are compared and validated for the best accuracy. The results of this study exhibit that LCD TV diffusion is mainly driven by consumers' word of mouth and 32-inch LCD TV remains to occupy the largest potential market among various size levels of LCD TVs. Previous LCD TV adopters persuade the potential ones to imitate the former in the TV transaction decisions. In particular, this model illustrates that LCD TV price reduction stimulates such imitating behaviors of successive LCD TV consumers. Due to the significance of the modeled price effect in LCD TV adoptions, the model with considering the effect of price performs better in fitness, prediction capability and parameter stability than the conventional one.

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### 1. Introduction

Since the popularity of liquid crystal display television (LCD TV) has soared in recent years, the growth of its diffusion has become progressively crucial in high technology fields. LCD TV output values, which occupy 46% of the whole value of large TFT-LCD industry, have reached 33.6 billion US dollars in 2007. Unlike pure consumer durable or technological commodities, LCD TVs possess the properties of both commodities. Because LCD TVs have widely spread as the main type of TV in households, they have been regarded as consumer durable products. Due to the continuous technical progress emerged in different generations, LCD TVs contain advantages of slimness, lightness and high resolution in comparison with traditional TVs (Hung, 2006) and are viewed as technological commodities.

Referring to pure technological commodities, DRAM or flash memory from the previous generation may be replaced completely by those from the next generation as revealed in previous studies (Bass, 2004; Li & Chiang, 2007; Norton & Bass, 1987). In those studies, product characteristics or functions of DRAM and flash memory

in various generations are similar and replaceable, so the market of old products diminishes in high speed. In contrast to such homogeneous products in prior literature, the size demand of LCD TV is heterogeneous. Because the space is fixed in consumers' house, people who live in small space tend to purchase small-sized LCD TV. Even if the emerging technology enables TFT-LCD manufacturers to utilize sophisticated techniques to produce large-sized LCD TVs, people living in a small space are not likely to substitute small-sized LCD TV for larger ones. Due to the space limitations or consumer preference, LCD TVs from the previous generation may not be replaced completely by those from next generations. The fact that LCD TV market is divided into distinct groups of buyers who might require different size levels of LCD TVs is consistent with "market segmentation" hypothesis (Kotler, 2009; Wendell, 1956). The coexistence among different size levels of LCD TVs is unique in pure technological products. LCD TVs are products which possess properties of durable and high-technological commodities under "market segmentation" framework.

In particular, prices of LCD TV panels decrease with time as their productivity by degrees expands, curtails their unit cost and achieves the economy of scale. As seen in Fig. 1, even though the price has been standardized in terms of average prices per square meters, the unit price appeared greater for large size LCD TV panels

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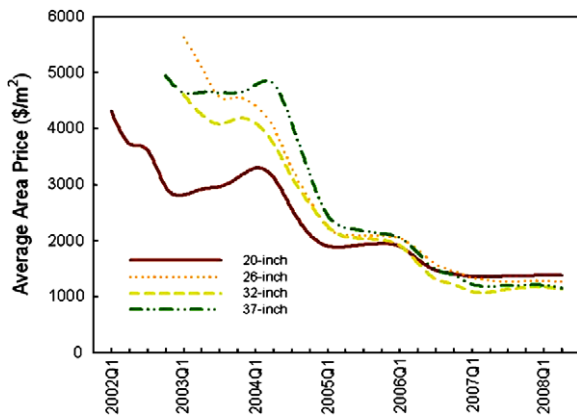


Fig. 1. The pattern of average area price (average price per square meters) of various levels of LCD TV panels (Data source: DisplaySearch databases).

than smaller ones as the LCD TV panels newly entered the markets. The unit price of various size levels of LCD TV panels little by little converge to be approximately the same only when the productivity of each size level reaches the economy of scale. Teo, Chu, Lee, Bang, and Suratkal (2003) emphasizes low price is essential factor that drives LCD TV sales and enables LCD TVs to become a household appliance for more and more families. It is worthwhile to highlight how price reductions stimulate the growth of LCD TVs. Hence, this paper intends to formulate a dynamic growth model that incorporates price elements to explore the diffusion of LCD TVs.

A substantial research effort has focused on the dynamic growth of technological change and product diffusion (Sohn, Kim, & Hwang, 2008). The growth model originated in Bass (1969) is mainly utilized to interpret the diffusion of the durable consuming goods, for instance, black-and-white TVs or color TVs (Jain & Rao, 1990; Kalish & Lilien, 1986; Kamakura & Balasubramanian, 1988). The internal and external influences of diffusion evolutions are precisely captured in these researches. The internal influence is defined as the interpersonal communications among consumers. Previous product adopters exercise influence on potential product adopters by persuading the latter to imitate the former in their purchasing decision. In other words, the internal influence, driven by the “word of mouth”, illustrates the imitating behavior of the product adoptions. On the other hand, the external influence includes product advertising and business announcements from the enterprises. It elucidates the innovative behaviors of product adoptions. Because the effects of innovation, imitation, and potential market factors are all considered in Bass (1969) growth model, this theory is widely spread in the sphere of social science (Bass, 2004; Mahajan, Muller, & Bass, 1990; Meade & Islam, 2006; Rogers, 2003; Ruiz, Leeflang, & Wieringa, 2006). Previous literature extends to apply diffusion theory in the market dynamics concerning semiconductor components (Li & Chiang, 2007; Norton & Bass, 1987), franchising (Ruiz & Leeflang, 2006), movies (Ruiz & Más, 2001), industrial clustering (Tsai, 2008) and foreign direct investment decisions (Tsai, 2010), and cumulative purchase products (Kang, Kim, Han, & Yim, 1996).

However, although preceding studies such as Bass (2004) have proposed the perspective concerning the market dynamic of the specific product which possesses properties of both “consumer durable” and “high-technological commodity”, the DRAM products in Bass (2004) is not under the “market segmentation” framework with price effect taken into consideration. In particular, Bass (2004) chiefly discussed the replacement of products of previous generation by that of the next generation; the empirical evidence of price impact on products of different generations coexisting in the market is not provided. For these reasons, our investigation takes

“market segmentation” framework as the basis, and incorporates the price effect to accentuate the market dynamic of the multi-generation product which possesses properties of both “consumer durable” and “high-technological commodities”. Modeling price effects for the diffusion of such dual-attribute products may benefit the investigation of market evolutions of LCD TVs.

In this work, we relax the restrictive assumptions of constant internal influence in the conventional growth model for diffusion of LCD TVs all over the world. In original Bass (1969) setting, the diffusion of product is assumed to be unaffected by prices; however, what accompanies the diffusive growth of different sizes of LCD TV panel is the immediate advent of lower prices. Price reductions of LCD TVs accelerate the internal influence of LCD TVs diffusion. As the prices of LCD TV panels keep reducing, the successive consumers are more encouraged by the previous consumers’ general praises to buy LCD TVs. Since the time-varying internal influence should be correlated to LCD TV panel price, the estimation may be biased if the LCD TV panel market evolutions are calculated within restrictive Bass model, in which the internal influence is assumed to be fixed. Thus, we are motivated to specify the internal influence of each generation of LCD TVs as a function of its price reduction, since each generation of LCD TVs occupies its own market share independently under market segmentation framework. Although previous studies highlight price in determining internal influence dynamics (Mesak, 1996; Mesak & Berg, 1995; Parker, 1992) in the growth model, the products combining the attributes of durables and high-technology products under the market segmentation framework have never been well discussed. This is the foremost study that applies a growth model combining the impact of price on imitating behaviors of potential consumers to explain the diffusion of a specific commodity, which integrates dual characteristics of durable and high-tech commodities. According to Tversky and Kahneman’s (1974) anchoring and adjustment heuristic theory, our model presumes that consumers regard the initial price, the price at the time point when each modified type of LCD TV is first to be promoted on sale, as the “reference point”. Later when the price drops, consumers will compare the new price with the “reference point”. The more the price drops, the more will the successive adopters be inclined to follow previous adopters to purchase LCD TVs. In our article, the imitative behavior of each size of LCD TVs is specified to be related to its individual price drop under market segmentation.

The price impact in our work is aimed at the imitative behaviors according to the characteristics of LCD TVs. Eventually, LCD TVs are household TVs, so their potential market size corresponds to household number upon a multiplicative relation. Potential market dynamics of LCD TVs can hardly be driven by price reduction, in contrast to the price impact on potential market dynamics of other products (Bhargava, Bhargava, & Jain, 1991; Horsky, 1990; Kamakura & Balasubramanian, 1987; Parker, 1993). In addition, this work employs realistic price data of global LCD TVs to clarify the LCD TV evolutions precisely. Lee, Cho, Lee, and Lee (2006) have recognized prices as the inevitable factors in LCD TV diffusions, so they assumed the price function of LCD TV as a decreasing function of time to state LCD TV market growth. Unfortunately, the pattern of average area price (price per unit) of various levels of LCD TV panels does not monotonically decrease with time, unlike the specification that Lee et al. (2006) presumed. In order to overcome the limitations of prior research, this investigation obtains the genuine price data to specify LCD TV internal influence as a function of price fluctuations.

This paper focuses on the global LCD TV panel shipments from the first quarter of 2002 to the second quarter of 2008. The aims of this study are to incorporate realistic price data to systematically inquire effects of innovation, imitation, price elasticity and potential market size in global LCD TV panel diffusions. The model forms

a nonlinear ordinary differential equation (ODE) and is solved numerically (Li & Chiang, 2007). The model parameters are thus optimized with respect to the collected data for the best accuracy. In other words, nonlinear least squares (NLS) method in numerical simulation programs employs a sequential searching technique to obtain parameter estimates. Consequently, numerical simulation can produce good estimates of the unknown parameters in the model with relatively small data set. Thus, it is a fairly well-developed theory for computing confidence, prediction and calibration intervals to answer questions. The quarterly LCD TV shipment set is relatively small because they are newly commercialized and spread surrounding 2002. It is thus more reliable to apply numerical simulations to explore the diffusive evolutions of technological commodities. In order to find out a generally recognized diffusion model that is appropriate for predicting LCD TV, this research goes into model fitting and prediction of different sizes of available LCD TVs. To validate the model's effectiveness, we analyze the model's goodness of fit, parameter stability, and forecast accuracy among models proposed in our study. We compare the results inferred from the modified model, which incorporate price factors, with those of Bass model. The proposed model is ultimately applied to forecast future shipment trajectory of the LCD TV panels.

The results of all the models clearly demonstrate the internal influence to be positive through consumers' consistent praises for 20-inch, 26-inch, 32-inch and 37-inch LCD TV panels. Previous LCD TV adopters erect a behavior model for potential ones by persuading the latter to imitate the former in purchasing decision. Also, we have discovered that the estimated LCD TV innovative coefficient will shrink as the panel size turns larger, with an exception for 20-inch panel. In contrast, the estimated imitation coefficient will increase as the panel size becomes larger. Particularly, the results of modified diffusion models exhibit that the decreasing LCD TV price stimulates the growth of internal influence and then facilitates more adoption of LCD TV. In general, the imitating tendency of potential consumers is substantially driven by the price cut. With the increasing of LCD TV size as a general phenomenon, the market extension of band-new larger-sized panels relies on price decline in transmitting consumer's personal perceptions of such products and accelerating their diffusions. Since this research has proved that price is an influential factor on LCD TV market dynamics, our revised model explicitly performs superior in fitness, prediction capability and parameter stability than Bass model. The findings can provide TFT-LCD panel manufacturers with a valuable insight about LCD TV diffusion characteristics and help them review the feasibility of their marketing strategies.

The organization of this paper is as follows. In the next section, the price model and solution procedure are rendered. In the third section, the results of coefficient estimations, parameter stability analysis, and forecast accuracy are provided. In the fourth section, the additional tests are conducted. Finally, we draw the conclusion.

## 2. Background, model and solution procedure

Faced with the shortening of product longevity, LCD TV enterprises have to undertake research and development (R&D) to create new product features to meet consumers' time-varying preference. At the same time, enterprises must promote these high-technological products as soon as possible to maintain their profits; otherwise, such heavy R&D costs could not be recovered. Due to pioneering technology inserted in LCD TVs, LCD TVs contain advantages of slimness, lightness, high resolution, larger viewable image area (with the same screen size), greater brightness and contrast, reduced glare, space-saving and reduced power consumption in comparison with other types of TVs (Hung, 2006). LCD TVs are widely spread as the supplements to the main TVs in households

(Teo et al., 2003), so consumers have gradually viewed high-tech LCD TVs as consumer durable products. From the consumers' perspectives, LCD TVs possess unique properties, which differ from other technological commodities.

Referring to pure technological commodities, prior literature illustrates consumers' repeating purchasing of products such as DRAM, Disk Drives, or Recording Media (e.g. Bass, 2004; Li & Chiang, 2007; Norton & Bass, 1987). Technological products evolve by generations. A new generation represents an improvement over the earlier generations so that consumers repeat the purchasing behavior when the latest product is launched. For example, DRAM chips range from the 4 kb chip in 1974 to the 64 MB chip in 2000. In the beginning, people had no choice but the 4 kb DRAM chips. As the emerging technology made 16 kb DRAM chips possible, the 16 kb DRAM chip, with its improved functions, attracted buyers. Thus, 4 kb DRAM chip was substituted by the successive 16 kb DRAM chip. The 4 kb DRAM chip market declined rapidly and the 16 kb DRAM chip market expanded as uses and applications grew. Because product characteristics or functions of DRAM in various generations are similar and replaceable, the market of previous generational products diminishes in high speed. In contrast to such homogenous products in prior literature, the size demand of LCD TV is heterogeneous. Most consumers would take panel size into consideration when making decisions on whether to buy a LCD TV or not. Because the space is fixed in consumers' house, people who live in small space tend to purchase small-sized LCD TV. Even if the emerging technology enables TFT-LCD manufacturers to utilize sophisticated techniques to produce large-sized LCD TVs, people living in a small space are not likely to substitute small-sized LCD TV for larger ones. Due to the space limitations or consumer preference, LCD TVs from the previous generation may not be replaced completely by those from the next generations.

In addition, LCD TV adopters, who put LCD TVs in various occasions such as public places, living room or bedroom, even have different needs and wants for distinct LCD TV sizes. The fact that LCD TV market is divided into distinct groups of buyers who might require different size levels of LCD TVs is consistent with "market segmentation" hypothesis (Kotler, 2009; Wendell, 1956). Although larger-sized LCD TVs might be used in exhibition halls in public places or living rooms of households, smaller-sized LCD TVs still fit for the small rooms in public places or household bedrooms. Product attributes or functions of LCD TVs are diverse among various size levels, so different spaces require different size levels of LCD TVs. Smaller-sized LCD TVs will not be fully substituted by larger ones. The coexistence among different size levels of LCD TVs is unique to pure technological products. LCD TVs possess properties of durable and high-technological commodities.

### 2.1. Bass model

The innovation diffusion models developed for sales forecasting in marketing are based on the purchase probability. The purchase probability describes the probability that an initial purchase will be made at time  $t$  given that no purchase has yet been made and is a linear function of the number of previous buyers. This statement is expressed as:

$$\frac{f(t)}{1 - F(t)} = p + qF(t), \quad (1)$$

where  $f(t)$  denotes the likelihood of a purchase being made at time  $t$ , and  $F(t)$  represents the fraction of the ultimate potential that has been adopted by time  $t$ . The parameters  $p$  and  $q$  represent the degree of intensity of the resource for the external and internal influences, respectively. The external influence,  $p$ , is determined by two elements: (i) the intrinsic tendency of the individual firm

to buy LCD TVs, and (ii) the external promotions or advertisings which encourage consumers to purchase LCD TVs. On the other hand, the internal influence represents the impact on the consumers' involvement through the contact with previous experienced LCD TV adopter, namely, the imitating behavior of LCD TV consumption. Such internal communication as interpersonal communication (interpersonal communication, interaction among members of a social system) is suited to influence behavior when various size levels of LCD TVs have already started on sale, and more interestingly, this imitating behavior helps to explain the acceleration of the diffusion process as a logic process.

From Eq. (1), these two coefficients,  $p$  and  $q$ , can be used to compare the differential internal and external influences among LCD TV panel diffusions. Using the assumptions of Bass model, we find that the dynamic change rate of the capital amount is proportional to the current amount. Thus, Eq. (1) can be expressed as

$$f(t) = [p + qF(t)][1 - F(t)] = p + (q - p)F(t) - q[F(t)]^2. \quad (2)$$

Thus,  $n(t)$  and  $N(t)$  are used to symbolize the adopter number and cumulative adopter number at time  $t$ , and Bass model can be developed as:

$$n(t) = \left( p + q \times \frac{N(t)}{M} \right) [M - N(t)], \quad (3)$$

where  $M$  is the ultimate potential market, and  $n(t)$ , which equals  $Mf(t)$ , represents the total number of purchases in the  $(0, t)$  interval. Notably, Bass models are subject to restrictive conditions. It is assumed that the parameters of internal influence do not change over time. However, as LCD TV prices drop, previous adopters are more likely to persuade the potential ones to consume LCD TV. It implies that the imitating inclinations should be positively sensitive to price reduction. The assumptions of constant internal influence violate the real situations, so the applicability of Bass model is limited.

## 2.2. The modified model that incorporates price factors

Prior studies verify that imitative behaviors (internal influences) are much greater than innovative behaviors (external influences) in product diffusions for consumer durables or technological products (Bass, 1969; Li & Chiang, 2007; Ruiz et al., 2006). Imitating behaviors and consumers' word of mouth play more important roles than innovative behaviors. Particularly, the decreasing prices further strongly encourage the successive consumers to follow general praises of previous consumers to buy LCD TVs. Price reduction is the key factor to strengthen the imitating behaviors of potential LCD TV adopters, so this study relaxes the restrictive assumption concerning constant internal influence. Our internal influence dynamics is specified as the function of price decline. The internal influence of LCD TV diffusion in our model is now expressed as Eq. (4):

$$q_t = q_1 \times (P_0 - P_t)^\delta. \quad (4)$$

In Eq. (4),  $P_t$  is the price at time  $t$ . We set up the time 0 as the time point when a modified type of LCD TV is first to be promoted on sale, so  $P_0$  is the initial price. Obviously, the term  $(P_0 - P_t)$  in Eq. (4) represents the price gap in the interval  $[0, t]$ , from the time point when a modified type of LCD TV is first to be promoted on sale ( $t = 0$ ) to time  $t$ . Because price reductions enhance the imitating behaviors of LCD TV consumptions, the coefficients of imitation, at period  $t$ ,  $q_t$  varies with LCD TV panel prices over time and is stated as a function of price reduction. The parameter  $\delta$  denotes the price elasticity, which represents the marginal effect of price reduction on internal influence. For this reason, we put the Eq. (4) into Eq. (3) and it can be rewritten as Eq. (5):

$$n(t) = \left( p + q_1 \times (P_0 - P_t)^\delta \times \frac{N(t)}{M} \right) [M - N(t)]. \quad (5)$$

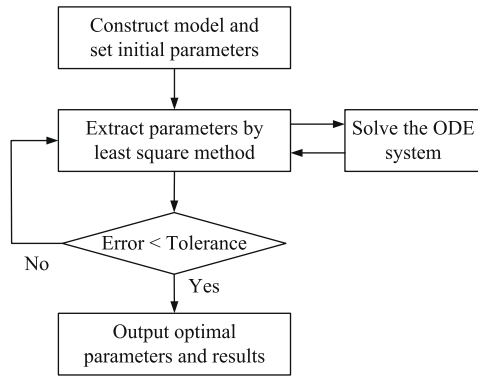
In Eq. (5), the imitating behavior depends on the price deduction and is not constant all the time. The positive price elasticity coefficient  $\delta$  accelerates the diffusions of LCD TV panels through price decline impact on consumers' imitating behaviors, so this paper makes use of this coefficient  $\delta$  to capture how price influences LCD TV panel growth dynamics. Eventually, LCD TVs are household TVs, so their potential market size corresponds to household number upon a multiplicative relation. Potential market dynamics of LCD TVs can hardly be driven by price reduction. Hence, the potential market is presumed to be unaffected by price reduction in our work.

Prior research argues that changes in prices and other decision variables will influence the diffusion process (e.g. Chen & Chen, 2007; Robinson & Lakhani, 1975). The difference between these two articles and our investigation is summarized in twofold in model specifications. First, Robinson and Lakhani (1975) or Chen and Chen (2007) assume that the price influences imitation, innovation and potential market, but their research do not distinguish the price impact on these three critical factors separately in diffusion process. To what extent the prices affect the coefficients of imitation, innovation and the potential market cannot be precisely identified from their settings. In contrast to Robinson and Lakhani (1975) or Chen and Chen (2007), the price impact in our work is aimed at the imitative behaviors according to the characteristics of LCD TVs, so our model set the imitation coefficient as the function of prices (Eq. (4)). Thus, our models can precisely identify how price influences the expansion of the imitation behaviors, thus contributing to market saturation.

Second, internal influence dynamics in our article is specified as the function of price gap in the interval  $[0, t]$ , from the time point when a modified type of LCD TV is first to be promoted on sale ( $t = 0$ ) to time  $t$ . The unit price of LCD TVs declines in high speed after LCD TVs are first to be promoted on sale ( $t = 0$ ). In Fig. 1, unit prices of various types of LCD TVs in 2005 decrease to half of that in 2003. Since the price drop dramatically, LCD TV consumers can memorize the initial prices  $P_0$  easily. According to anchoring and adjustment heuristic theory proposed by Tversky and Kahneman (1974), people start with an implicitly suggested reference point (the "anchor") and make adjustments to that number based on additional information. LCD TV consumers tend to regard the initial price  $P_0$ , the price at the time point when a modified type of LCD TV is first to be promoted on sale ( $t = 0$ ), as the reference point. The more the price divergence ( $P_0 - P_t$ ) is, the more will people feel the substantial price drop of the LCD TVs. Thus, successive adopters are more inclined to follow previous adopters to purchase LCD TVs. When the price divergence is greater, the price reduction impact on the "word of mouth" gets more apparent.

On the basis of anchoring and adjustment heuristic theory, this work specifies the price reduction as the price gap ( $P_0 - P_t$ ) in the interval  $[0, t]$ , from the time point when a modified type of LCD TV is first to be promoted on sale ( $t = 0$ ) to time  $t$ . Rather than the price difference in the interval  $[0, t]$ , Chen and Chen (2007) focus on the price change ratio in the interval  $[t - 1, t]$ . Their model ignores the initial price  $P_0$  because the price drop of color TVs, clothes dryers, and room air-conditioners is not as rapid as that of LCD TVs. People may hardly remember the initial price  $P_0$  of color TVs, clothes dryers, and room air-conditioners long time ago, and thus they would not apply the initial price  $P_0$  as the reference point to determine whether they will purchase these products.

The computational procedure for the simulation-based optimization method is adopted (Li & Chiang, 2007), as shown in Fig. 2. The process of computer simulation extracts parameters using the least square method. To solve the ODE numerically, a 4th-order



**Fig. 2.** A computational procedure for the simulation-based optimization methodology to solve and extract the dynamic system in this work.

Runge–Kutta algorithm (Burden & Faires, 2005) is implemented in the proposed scheme. Once the computed solution is obtained, it is calibrated with realistic data to yield an accurate simulation. If the tolerance of the result is greater than the error, the optimal parameters and results are outputted. Otherwise, a least square optimization technique enables the updating of modifying parameters for the next simulation.

To verify whether the numerical simulation performs better than analytical OLS regression proposed in Bass (1969), two different approaches, analytical OLS regression and numerical simulation are conducted to estimate parameters in Bass model. Their simulated results are calibrated with realistic data, by which the accuracy among the two approaches as well as the collected data is compared and validated. The accuracy comparison is conducted among Bass models based on numerical simulation and our modified models, which incorporate price factors, based on numerical simulation. This research verifies whether the modified model, which specifies the price factors and solved numerically, performs better than the conventional one.

**2.3. Parameter calculation**

After the parameters calculation, we further evaluate parameter stability and forecasting ability to decide whether the modified model that incorporates price factors (Eq. (5)) is appropriate to predict LCD TV panel shipments. For the goodness of fit analysis, we select R-square to make judgments. The model will have a better fitness if the R-square value of the fitted model is close to one. For the assessment of parameter stability, this paper checks whether the parameters can be estimated more stable and reliable by the modified model than by Bass model. This study follows the method proposed by Golder and Tellis (1998) to evaluate parameter stability of the modified model. We estimate each model persistently, starting with a data series and then adding one more period every time we re-estimate the parameter. This work re-estimates the parameter from the second quarter of 2007 to the second quarter of 2008. The two measures of parameter stability are expressed in Eqs. (6) and (7):

$$STAB1 = \frac{mean(\hat{\beta})}{Std(\hat{\beta})}, \tag{6}$$

and

$$STAB2 = \sum \left| \frac{\hat{\beta}_t - \hat{\beta}_{t-1}}{mean(\hat{\beta}_t)} \right| \frac{1}{K}, \tag{7}$$

where  $\hat{\beta}$  represents the parameter estimates and  $K$  the number of estimation periods.  $Std(\hat{\beta})$  and  $mean(\hat{\beta})$  denote the standard deviation

and means of the parameters. Hence, STAB1 captures fluctuations from the overall mean. This measure is “the mean of the estimates of the parameter divided by the standard deviation of estimates,” where the multiple estimates are obtained by adding an additional quarter to the data. STAB2 captures period to period fluctuations. This measure is “the average period to period change standardized by the mean of the parameters.” In theory, the higher STAB1 values and the lower STAB2 values indicate the model’s greater parameter stability. In this study, we will calculate STAB1 and STAB2 for the modified and Bass models to compare their parameter stability.

**2.4. Forecasting**

Two periods of the sampled data are examined; one is the training sample period and the other is the testing sample period. All the prediction models are developed by using the training sample of 20-inch, 26-inch, 32-inch and 37-inch shipments, with data ranging from the respective initial periods to the second quarter of 2007, and their levels of accuracy are compared with the test sample from the third quarter of 2007 to the second quarter of 2008. We apply the estimated parameters calculated from training sample to evaluate shipment orbits in test sample. We choose mean absolute percentage errors (MAPEs) of the cumulative and quarterly shipments in the test sample to compare the forecasting capability of the modified model with the conventional one. The calculated errors could manifest the results which method is more efficient.

**3. Results and discussion**

The global quarterly shipment units of LCD TV panels and the prices of global LCD TV panels in this study are obtained from DisplaySearch databases. The price has been standardized in terms of average prices per square meter. The period ranges from the first quarter of 2002 to the second quarter of 2008, totally 26 quarters in our sample. Because 20-inch, 26-inch, 32-inch, and 37-inch LCD TVs begin to be available to the market in different periods, the realistic amounts of shipment units are collected beginning from the first quarter of 2002, the first quarter of 2003, the first quarter of 2003, and the fourth quarter of 2002, for 20-inch, 26-inch, 32-inch, and 37-inch LCD TVs, respectively. Therefore, we contain 26, 22, 22 and 23 observations for 20-inch, 26-inch, 32-inch, and 37-inch LCD TVs, respectively.

**3.1. The results of parameter calculation**

We use the actual market and price data of 20-inch, 26-inch, 32-inch, and 37-inch LCD TV panel to fit the model respectively to estimate the model parameters of each size of LCD TV panels. The parameters we estimate include innovation coefficient  $p$ , imitation related coefficient ( $q$  for Bass model and  $q_1$  for the modified model), elasticity coefficient  $\delta$ , as well as the market potential  $M$ . In order to have a baseline of comparison, the actual data is also fitted within Bass model using analytical OLS and numerical methods, respectively to estimate the parameters. The detailed results are shown in Table 1. For models based upon analytical OLS regression and simulation solutions, no matter what size LCD TV is, the results of parameters estimation show that imitation coefficient  $q$  is much greater than innovation coefficient  $p$ . This suggests that the imitating behaviors dominate the product diffusions. For the estimation of potential market size  $M$  of each size LCD TV, 32-inch LCD TV panels have the greatest potential market. This implies that 32-inch LCD TVs remain the mainstream in LCD TV industry.

**Table 1**  
The parameter estimation for Bass model and the modified model. Parameters of the innovation behavior  $p$ , price elasticity  $\delta$ , and potential market  $M$  are systematically estimated. For Bass model, imitation coefficient  $q$  is assumed constant, while time-variant  $q_t$  is specified for the modified model that incorporates price factors, namely,  $q_t = q_1 \times (P_0 - P_t)^\delta$ .

Size level	Model	$p$	$q_1$ (or $q$ )	$\delta$	$M$ (Thousand units)	Adjusted $R^2$
20-inch	Bass (OLS) <sup>a</sup>	0.0008	0.2549	–	36,042	0.7944
	Bass (numerical) <sup>a</sup>	0.0013	0.2894	–	32,750	0.9993
	Modified model (numerical) <sup>b</sup>	0.0018	0.1610	0.0656	34,458	0.9998
26-inch	Bass (OLS) <sup>a</sup>	0.0021	0.1969	–	65,684	0.9716
	Bass (numerical) <sup>a</sup>	0.0017	0.1987	–	79,019	0.9972
	Modified model (numerical) <sup>b</sup>	0.0021	0.1424	0.0572	53,332	0.9977
32-inch	Bass (OLS) <sup>a</sup>	0.0016	0.2493	–	161,078	0.7057
	Bass (numerical) <sup>a</sup>	0.0008	0.2416	–	237,834	0.9957
	Modified model (numerical) <sup>b</sup>	0.0010	0.1585	0.0693	152,250	0.9978
37-inch	Bass (OLS) <sup>a</sup>	0.0004	0.3044	–	35,911	0.9943
	Bass (numerical) <sup>a</sup>	0.0004	0.2870	–	47,046	0.9973
	Modified model (numerical) <sup>b</sup>	0.0005	0.1619	0.0857	34,854	0.9988

$$^a n(t) = \frac{dN(t)}{dt} = \left[ p + q \frac{N(t)}{M} \right] * [M - N(t)].$$

$$^b n(t) = \left( p + q_1 * (P_0 - P_t)^\delta * \frac{N(t)}{M} \right) [M - N(t)].$$

In regards to the modified model that incorporates price factor, price elasticity coefficient  $\delta$  is all positive. Previous consumers who have adopted LCD TVs are more inclined to recommend potential consumers to successively buy LCD TVs as the prices of LCD TV panels drop. Namely, price decline of LCD TV strengthens the influence of general praise from the experienced LCD TV adopters, so the imitating behaviors of successive adopters become more prevalent. This accelerates the diffusions of LCD TV panels. In addition, we further apply Eq. (4) to calculate the time-variant imitation coefficient  $q_t$  over time,  $q_t = q_1 \times (P_0 - P_t)^\delta$ , for the various sizes of LCD TV panels. As the result shown in Fig. 3, we can find that the imitation coefficients increase gradually for 20-inch, 26-inch, and 32-inch LCD TV panels. Combining the price trend depicted in Fig. 1 and imitating fluctuations denoted in Fig. 3, the decrease in price will enlarge imitation coefficient  $q_t$  and promote the LCD TV sales. In fact, the price of the 32-inch of LCD TV panel has declined from 4606 US dollars (per square meters) in the first quarter of 2003, the time when 32-inch LCD TV was newly available to the market, to 1121 dollars in the second quarter of 2008. Meanwhile, the shipments of LCD TV panels have grown from 4000 to more than 10,000,000 according to the statistics in DisplaySearch database. Consistent with our estimated results, causal relations are also observed between LCD TV panel shipments and prices for 20-inch, 26-inch and 37-inch LCD TVs. On the other hand, the prices of LCD TV panels increased dramatically surrounding 2004

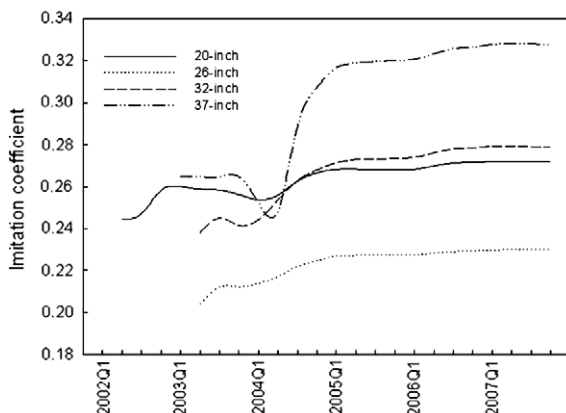
for 37-inch LCD TV panels, so the imitation coefficient is estimated to drop. After 2004, the imitation influence and adoptions of 37-inch LCD TV aggressively expands due to price reduction. This all proves why the modified model, which considers price factors, is more stable to capture the diffusion pattern. More interestingly, we can also discover that the large size LCD TV panel's imitation coefficient (32-inch and 37-inch) will be almost greater than smaller ones (20-inch and 26-inch). The implication is that the imitation behavior is more critical for spreading large size LCD TV panels.

The results of Table 1 show that the imitating coefficient  $q_t$  is much greater than innovation coefficient  $p$  in the modified model, consistent with the results inferred from Bass model. This once again suggests the imitating behaviors dominate the product diffusions. From the estimation of potential market  $M$  of each size level of LCD TVs, 32-inch LCD TV panels contain the greatest market share. The findings are consistent with those inferred from Bass model as well.

Referring to the goodness of fit analysis, the adjusted R-square of Bass model is only 0.7944 and 0.7057, respectively, for 20-inch and 32-inch LCD TV panels based upon the analytical OLS regressions. On the other hand, the adjusted R-square of Bass model is over 0.99 based on the numerical solutions. This concludes that numerical methods exhibit much better fitness quality than analytical OLS regression method. Comparing the adjusted R-squares of Bass model (Eq. (3)) with the adjusted R-squares of the modified models, which incorporate price factors (Eq. (5)), the latter is higher than the former. Focusing on the two models based on numerical methods (Eqs. (3) and (5)), we prove better quality of the modified model to fit the LCD TV panel diffusion than Bass model.

### 3.2. The sensitivity of calculated parameters

Because the goodness of fit for numerical solutions performs better than that for the analytical OLS regression solutions, the parameter stability (in this section) and forecast ability (in the next section) are conducted for the two numerical models, Bass model and our model. Comparison of parameter stability between Bass model and the modified model which considers the price factors is shown in Table 2. In theory, the higher STAB1 values indicate that the model presents greater parameter stability, and the lower STAB2 values indicate that the model presents greater parameter stability (given that STAB2 captures instability). From Table 2, we can obviously observe that the parameter stability indicators, STAB1, of the external and internal influence parameters ( $p$  and  $q$



**Fig. 3.** The imitation coefficient  $q_t$  versus time for the modified model which incorporates price factors at various levels of LCD TV panels. The time-variant imitation coefficient is  $q_t$  calculated by  $q_t = q_1 \times (P_0 - P_t)^\delta$ .

**Table 2**

The results of parameters stability indicators (STAB1 and STAB2) for the modified model which considers price factors. The higher STAB1 values and the lower STAB2 values present greater parameter stability.

Size level	Bass model <sup>a</sup>			Modified model <sup>b</sup>			
	<i>p</i>	<i>q</i>	<i>M</i>	<i>p</i>	<i>q</i> <sub>1</sub>	$\delta$	<i>M</i>
<i>20-inch</i>							
STAB1 <sup>c</sup>	38.42	60.74	43.22	50.05	159.28	46.00	38.85
STAB2 <sup>d</sup>	0.016	0.010	0.013	0.012	0.003	0.012	0.015
<i>26-inch</i>							
STAB1 <sup>c</sup>	11.96	36.49	9.11	18.97	79.14	25.29	20.62
STAB2 <sup>d</sup>	0.073	0.022	0.096	0.035	0.010	0.045	0.048
<i>32-inch</i>							
STAB1 <sup>c</sup>	4.97	22.37	10.79	12.59	79.03	18.61	11.02
STAB2 <sup>d</sup>	0.122	0.032	0.078	0.046	0.014	0.054	0.103
<i>37-inch</i>							
STAB1 <sup>c</sup>	5.70	22.91	6.73	38.68	70.31	11.67	6.60
STAB2 <sup>d</sup>	0.126	0.057	0.201	0.031	0.013	0.093	0.181

$$^a n(t) = \frac{dN(t)}{dt} = \left[ p + q \frac{N(t)}{M} \right] [M - N(t)].$$

$$^b n(t) = \left( p + q_1 * (P_0 - P_t)^\delta * \frac{N(t)}{M} \right) [M - N(t)].$$

$$^c STAB1 = \frac{\text{mean}(\hat{\beta})}{\text{standard dev.}(\hat{\beta})}$$

$$^d STAB2 = \sum \left| \frac{\hat{\beta} - \hat{\beta}_{-1}}{\text{mean}(\hat{\beta})} \right| \frac{1}{k}$$

(*q*<sub>1</sub>) are greater for the modified models than those for Bass models. In addition, the other parameter stability indicators, STAB2, of the external and internal influence parameters (*p* and *q* (*q*<sub>1</sub>)) are smaller for the modified models than those for Bass models. Parameters of imitating and innovative behaviors in the modified model are more stable than those of Bass model for each size of LCD TV panels. This once again supports that the modified model in which price factors are involved is more stable to interpret the internal and external influence of LCD TV panel diffusions.

3.3. The results of forecasting

In this section, the parameters of Bass and our modified models are numerically simulated using the training sample. Then, we apply the estimated parameters to evaluate shipment orbits in test sample (data from the third quarter of 2007 to the second quarter of 2008). The MAPEs of cumulative and quarterly shipments in test sample are thus computed and exhibited in Table 3. No matter which size of LCD TV panel is, MAPEs of cumulative shipments in the modified models are lower than 10%. However, MAPEs of cumulative shipments in Bass model are more than 10% for 32-inch LCD TVs. In regards to the quarterly shipments, the MAPEs of the modified models are below 15% for all size levels of LCD TVs in

**Table 3**

Mean absolute percentage prediction errors (MAPEs) of LCD TV panel shipments by using Bass and the modified models.  $MAPE = \frac{1}{n} \sum_{t=1}^n \left| \frac{Y_t - \hat{Y}_t}{Y_t} \right|$ , where *Y*<sub>*t*</sub> and  $\hat{Y}_t$  represent the realistic and predicted FDI at time *t*.

Size level	Model	MAPEs of cumulative shipments (%)	MAPEs of quarterly shipments (%)
20-inch	Bass model <sup>a</sup>	2.76	13.64
	Modified model <sup>b</sup>	2.88	14.74
26-inch	Bass model <sup>a</sup>	3.27	7.37
	Modified model <sup>b</sup>	4.72	13.01
32-inch	Bass model <sup>a</sup>	10.16	36.47
	Modified model <sup>b</sup>	2.48	8.92
37-inch	Bass model <sup>a</sup>	5.11	27.89
	Modified model <sup>b</sup>	4.21	10.16

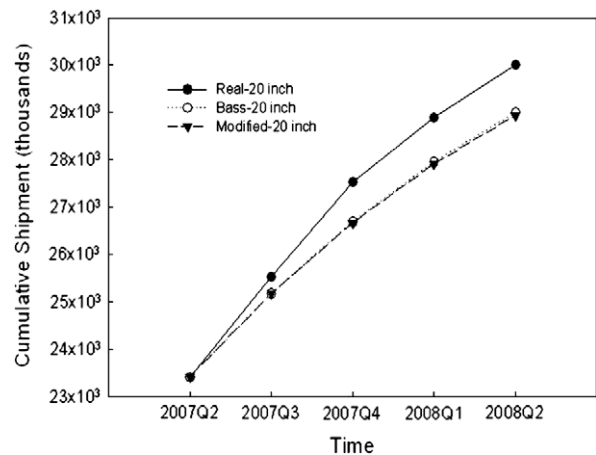
$$^a n(t) = \frac{dN(t)}{dt} = \left[ p + q \frac{N(t)}{M} \right] [m - N(t)].$$

$$^b n(t) = \left( p + q_1 * (P_0 - P_t)^\delta * \frac{N(t)}{M} \right) [M - N(t)].$$

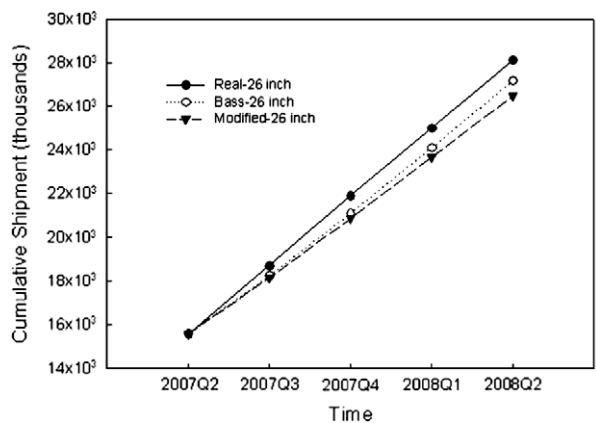
the modified models, while over 15% for 32-inch and 37-inch LCD TV panels in Bass model. It is inferred that the modified model is more accurate in forecasting than Bass model. In both perspectives of cumulative and quarterly shipments, the modified model performs superior to Bass model. Price elements incrementally validate the predictions of LCD TV panel shipments.

Comparison of simulated and realistic shipments among 20-inch, 26-inch, 32-inch and 37-inch LCD TV panels is additionally denoted from Figs. 4–7. The computed shipments versus the time for the calculation with Bass and modified models are plotted. Figs. 6 and 7 show the results for the 32-inch and 37-inch LCD TV panels; the Bass model's simulated shipments shift away from the realistic shipments. The simulated shipments of modified model are closer to the actual shipments than the Bass model's simulated shipments for 32-inch and 37-inch LCD TV panels.

Although the prediction ability of the modified model is not as good as that of Bass model for the 20-inch or 26-inch LCD TV panels, the simulated error difference is relatively minor. Martin and Witt (1989) explain that the forecasting capacity of a model is “excellent” as MAPE is smaller than 10% (MAPE < 10%). Forecasting capacity is “good” as MAPE locates in the interval [10%, 20%] (10% < MAPE < 20%). Forecasting capacity is “reasonable” as MAPE is in the interval [20%, 50%] (20% < MAPE < 50%). Although our



**Fig. 4.** Comparison of simulated and realistic shipments versus the time among the realistic data, Bass model simulation, and the simulation of modified model for 20-inch LCD TV panels.



**Fig. 5.** Comparison of simulated and realistic shipments versus the time among the realistic data, Bass model simulation, and the simulation of modified model for 26-inch LCD TV panels.

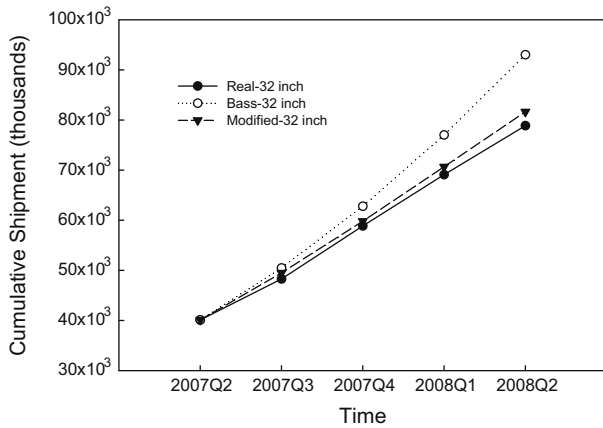


Fig. 6. Comparison of simulated and realistic shipments versus the time among the realistic data, Bass model simulation, and the simulation of our model for 32-inch LCD TV panels.

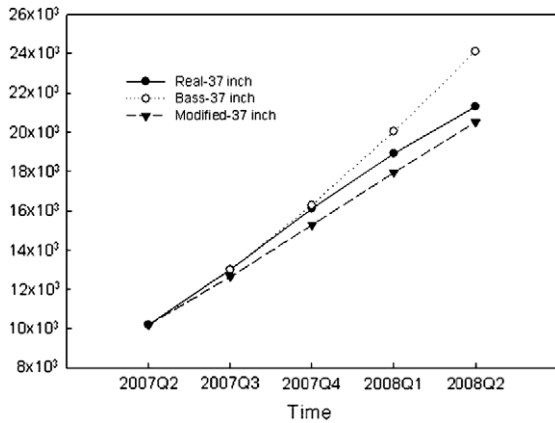


Fig. 7. Comparison of simulated and realistic shipments versus the time among the realistic data, Bass model simulation, and the simulation of our model for 37-inch LCD TV panels.

modified model does not perform better than Bass model for 20-inch and 26-inch LCD TVs, the forecast ability of both models is “excellent” in predicting the cumulative shipments of 20-inch and 26-inch LCD TVs according to [Martin and Witt \(1989\)](#) criteria. The forecast ability of our proposed model also maintains to be “good” in predicting the quarterly shipments of 20-inch and 26-inch LCD TVs. The MAPE difference is minor when comparing Bass and our modified model.

However, when using Bass model, the simulated errors of the 32-inch and 37-inch LCD TV panels are more explicit. The MAPE of Bass model is greater than 20% for the quarterly shipment of 32-inch and 37-inch LCD TVs. The forecasting ability of Bass model only belongs to “reasonable” level and inferior to that of our proposed model, which incorporates price elements. Because in reality, the cumulative shipments in test sample of 32-inch LCD TVs are twice greater than those of the other size levels of LCD TVs, the forecast accuracy of the mainstream 32-inch LCD TVs is more crucial than that of other size levels of LCD TVs from the viewpoints of market shares.

Our proposed model is superior to Bass model in predicting 32-inch and 37-inch LCD TV shipment, while slightly inferior in forecasting 20-inch and 26-inch LCD TV shipment. The possible interpretation is that the price decline was not obvious when LCD TVs initially entered the markets. Because 20-inch and 26-inch LCD TVs are brought into market earlier, the price impact on their dif-

fusions are limited. Thus, the modified model cannot be more accurate than bass model by considering the price decline factors. As the 32-inch and 37-inch LCD TVs entered into the market, LCD TV price declined dramatically and demands for LCD TV grew substantially. As LCD TVs prevailed, price played a more and more important role than in the earlier stage when LCD TVs first entered the market. As a result, the modified model, which incorporates price factors, performs better than Bass model. The evidence has confirmed the suitability of our modified models in determining mainstream LCD TV shipment trajectory.

### 3.4. Forecast of the future shipments

From the aforementioned findings, we conclude that the modified model proposed in this study presents better performance than Bass model in fitness, forecasting capacity, and parameter stability. That is, by considering price factor into diffusion model, a good tool has been developed to predict the future of LCD TV panel market. This work further predicts LCD TV panel’s shipments from the third quarter of 2008 to the second quarter of 2009. The forecast trajectory of cumulative and quarterly shipments is shown in [Figs. 8 and 9](#). The cumulative adoption of LCD shipments will continue to grow, and 32-inch LCD TV will particularly keep its mainstream position in the market. The cumulative adoption of 32-inch LCD TV panels will reach 117 million in the second quarter of 2009 and the quarterly adopters of 26-inch and 37-inch LCD TV panels will reach 40 million and 30 million, respectively. Furthermore, the market of 20-inch LCD TV panels will approach saturation point. This means that 20-inch LCD TV panels will fade out from the LCD TV market in the near future. Although our model has expected declining quarterly adoptions of each size of LCD TV panels in next four quarters, the financial crisis which suddenly occurred surrounding 2008 all over the world might reduce the public purchasing power and strongly strike LCD TV market in the future as well. Potential market size in Bass growth model should be considered as a function of macroeconomic factors during the financial crisis periods.

## 4. Additional test

Some researchers may think that the forecasting performance of our proposed model should be compared with more recent models, for instance, [Bass \(2004\)](#) substitution models which focus on the substitution of previous generation of high-technology products by the successive ones. This paper has applied the [Bass \(2004\)](#)

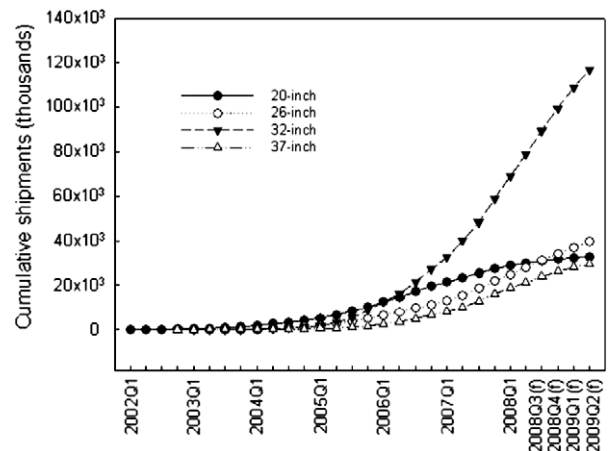


Fig. 8. The cumulative shipment forecast of LCD TV panels from the third quarter of 2008 to the second quarter of 2009.



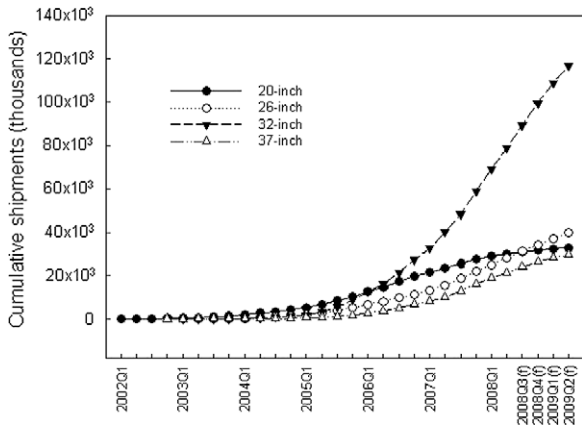


Fig. 9. The quarterly shipment forecast of LCD TV panels from the third quarter of 2008 to the second quarter of 2009.

substitution models to explore the imitation behaviors, innovation behaviors and potential markets in LCD TV industry in our additional tests. In theory, the parameters of imitation behaviors, innovation behaviors and potential markets are positive. However, the potential market sizes are estimated unreasonably negative according to our estimation based upon Bass (2004) substitution models. The possible interpretation is that the shipments of multi-generation LCD TVs violate the assumption of Bass (2004) substitution models.

In Bass (2004) model, multiple generations of products are assumed to enter into markets successively. Time lag exists among various generations because the latter generation needs time to improve over the previous one. A good example is that DRAM chips which range from the 4 kb chip in 1974 to the 64 MB chip in 2000. However, the 20-inch, 26-inch, 32-inch and 37-inch LCD TV enter the market almost at the same time. The 20-inch LCD TVs are gradually accepted by the markets around the first quarter of 2002, while 26-inch, 32-inch and 37-inch LCD TVs all entered the market by more than 4000 units around the first quarter of 2003. There is no obvious time lag among different sizes of LCD TVs. Besides, in Bass (2004) model, the earlier generation is replaced completely by those from the next generation because these products contain homogeneous functions. However, 20-inch, 26-inch, 32-inch and 37-inch LCD TVs exist simultaneously from 2003 until today because they have their own segmented market.

This paper further chooses another recently-developed model, Lotka–Volterra model to forecast the shipments of the existing sizes of LCD TVs. Tang and Zhang (2005) have analyzed the quarter revenues of advanced micro devices (AMD) and Intel by Lotka–Volterra equations. Their research incorporated competition between two vendors of central processing units (CPUs) to explain the product diffusion. In this additional test, the Lotka–Volterra model is applied to forecast the LCD TV shipments. The Lotka–Volterra model uses the logistic equation and a term that accounts for the interaction with others (Tang & Zhang, 2005; Tsai & Li, 2009). The interaction between two sizes of LCD TVs can be expressed by the following two differential equations:

$$\frac{dX}{dt} = (a_1 - b_1X - c_1Y)X = a_1X - b_1X^2 - c_1XY, \tag{8}$$

and

$$\frac{dY}{dt} = (a_2 - b_2Y - c_2X)Y = a_2Y - b_2Y^2 - c_2YX, \tag{9}$$

where  $X$  and  $Y$  are the shipments of two competing LCD TVs at time  $t$ ;  $X^2$  and  $Y^2$  are the same size of LCD TVs interacting with itself;  $XY$

and  $YX$  are interactions between different sizes of LCD TVs;  $a_i$  is the logistic parameter of geometric growth;  $b_i$  is the limitation parameter of the niche capacity; and  $c_i$ , generally called the coupling coefficient, is the parameter for interaction with others. The multi-mode form of competition can be captured by coefficient  $c_i$  for two LCD TVs.

To use discrete time data, one must convert the continuous Lotka–Volterra model into a discrete time version. Eqs. (8) and (9) can be transformed into the following difference equations (Leslie, 1957):

$$X(t + 1) = \frac{\alpha_1 X(t)}{1 + \beta_1 X(t) + \gamma_1 Y(t)}, \tag{10}$$

and

$$Y(t + 1) = \frac{\alpha_2 Y(t)}{1 + \beta_2 Y(t) + \gamma_2 X(t)}. \tag{11}$$

Since the competition between LCD TVs of similar sizes is the greatest, this paper constructs the Lotka–Volterra models by pairing LCD TVs of similar sizes. The four sizes of LCD TVs constitute three pairs (20-inch and 26-inch, 26-inch and 32-inch, 32-inch and 37-inch), in order to predict the LCD TV shipment by incorporating the reciprocal influence among these three pairs. The parameters of these Lotka–Volterra models are estimated using quarterly LCD TV shipments from the first quarter of 2003 to the second quarter of 2007. Then the forecasted quarterly LCD TV shipments from the third quarter of 2007 to the second quarter of 2008 are compared with actual quarterly shipments. The MAPE of Lotka–Volterra model during the test period is computed and listed in Table 4.

The comparison results show that the MAPEs of the Lotka–Volterra models are much larger than that of our modified model for shipments of 32-inch and 37-inch LCD TVs. On the other hand, the MAPE of the Lotka–Volterra model is lower for the pairs of 20-inch and 26-inch LCD TV shipments. Although our modified model does not perform better than Lotka–Volterra model for 20-inch and 26-inch LCD TVs, the forecast ability of both models is “excellent” in predicting the cumulative shipments of 20-inch and 26-inch LCD TVs according to Martin and Witt (1989) criteria. Because in reality, the cumulative shipments in test sample of 32-inch LCD TVs are twice larger than those of the other size levels of LCD TVs, the forecast accuracy of the mainstream 32-inch LCD TV is more crucial than that of other size levels of LCD TVs in terms of market shares. The modified model, which incorporates price factors, is more reliable to predict LCD TV shipments than other models.

### 5. Conclusions

This study suggested an alternative model to overcome the limits of the traditional Bass diffusion model, mainly in terms of incorporating price factors and estimating the demand for products. This is the first and genuine study that applied a growth model considering prices impact on potential consumers’ imitating

Table 4

Mean absolute percentage errors (MAPEs) of cumulative shipments by using Lotka–Volterra model. The four sizes of LCD TVs constitute three pairs (20-inch and 26-inch, 26-inch and 32-inch, 32-inch and 37-inch) of Lotka–Volterra equations and the three pairs of MAPEs are computed by  $MAPE = \frac{1}{n} \sum_{t=1}^n \frac{|Y_t - \hat{Y}_t|}{Y_t}$ .

Size level	Lotka–Volterra model		
	20-inch and 26-inch (%)	26-inch and 32-inch (%)	32-inch and 37-inch (%)
20-inch	0.66		
26-inch	1.17	6.91	
32-inch		11.09	5.64
37-inch			16.54

behaviors to explore the diffusive evolutions for various size levels of LCD TV panels. The modified model considered price factors and formed a nonlinear ordinary differential equation. To testify the model's effectiveness, the goodness of fit, parameter stability, and prediction ability of the modified models, which incorporated price factors, based on numerical simulation were compared with those of Bass model based on numerical simulation.

For all the models in our research, the results of parameters estimation have exhibited that imitation coefficients appear much greater than innovation coefficient. This suggests the imitating behaviors inevitably dominate the LCD TV product diffusions. Particularly in the modified model, which incorporates price factor, the consumer's imitating tendency has been found increasing with the price decline. In general, the diffusion dynamics of consumer durable products depends more on word of mouth during their long life cycle. Although LCD TV panels dually behave the property of high-technological and consumer durable products, the imitating impact is substantially driven by price reduction. The results imply that LCD TV manufacturers can expand LCD TV sales through price reductions to accelerate recovering their R&D and production costs as soon as possible. Especially, imitating behavior has become more essential for the large size (32-inch and 37-inch) LCD TV panel diffusion, while their innovation behavior is not as influential as that in the smaller size (20-inch or 26-inch) LCD TV. 32-inch LCD TV panels have been measured to contain the largest potential market, which implies their mainstream position in LCD TV industry.

In addition, the results of parameter stability has unveiled that the modified model, which holds price factors, are more stable in coefficient estimation than Bass model for each size of LCD TV. This once again implies that the modified model proposed in this study is more reliable to interpret the LCD TV market evolutions. Finally, the prediction errors have been found much smaller for the modified model with price factors than the restricted Bass models. These evidences concerning parameter stability and prediction error analysis have strongly affirmed the usefulness of the element, price, in stating LCD TV market growth.

So far, price impact on imitating behaviors has been facilitated in Bass growth model to illustrate LCD TV market dynamics. However, the financial crisis that suddenly haunted the world surrounding 2008 might strike LCD TV market in the future. In further research, therefore, potential market size can be specified as a function of macroeconomic factors when any financial crisis breaks out.

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