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Pricing Patterns over Product Life-Cycle and Quality Growth at Product Turnover: Empirical Evidence from Japan*

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Abstract

This paper examines pricing patterns over the product life-cycle and quality growth at the time of product turnover regarding a wide range of durable consumer goods sold in Japan. Applying hedonic regressions with time dummies to large granular data sets obtained from *Kakaku.com*, the most popular price comparison website in Japan, we find out that sellers tend to raise product prices more than those justified by quality improvements to ensure the profitability at product turnover. A glance at the pricing patterns reveals that the prices of new products decrease gradually with the elapse of time, however, the pace of falling in prices varies considerably among commodities. The quality improvement ratio, which measures the contribution of quality growth to the price difference between matched pair of a new product and an old one by commodities, exhibits a unimodal distribution slightly fat-tailed to the right. The mode value of the distribution is about 0.5-0.6 for home electrical appliances and about 0.6-0.7 for digital consumer electronics. Those results provide an empirical support to the existing quality adjustment method in the field of the price index, so-called *50% rule*, which has been implemented by some statistical agencies. Our findings bring significant implications for improving quality adjustment methods under uncertainty of quality evaluation and lead to the better understanding of the firms' price setting behavior.

Keywords: price index, quality adjustment, price setting, hedonic approach
JEL Classification: C43, D22, L15

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I. Introduction

The price index is constructed by indexing the constant-quality price of goods and services with the price at the base point in time as 100. The index is created by selecting representative products in the market and surveying their transaction prices continuously each period. If a representative product shifts from the old product to the new product, the target product for the price survey is changed without delay. The issue here is how we should link the prices of new products and old products in producing the index.

The price index captures changes in the price for the product with the same quality. Therefore, if there is a difference in quality between new products and old products, the index reflects the residue after subtracting the price difference due to the difference in quality from the whole price difference between new products and old products. This is the process of quality adjustment which is essential in compiling the price index.

It is said that prices of durable consumer goods have a tendency to be decreased gradually over the product life-cycle. In addition, the price of new products at a product turnover tends to be more expensive than that of old products. Such a price difference between new products and old products can be decomposed of the price difference corresponding to the improvement in the new product's quality (quality growth) and pure price increase intended to ensure the profitability. For the practice of producing the price index, it is a matter of important concern (a) how large the magnitude of price decrease is over the life cycle, and (b) how big is the price difference corresponding to quality growth and pure price increase. However, as far as the authors know, there is little empirical research focusing on the detailed price transition of individual products for the purpose of improving the precision of the price index.

Accordingly, in this paper, targeting at individual products included in popular 20 commodities of home electrical appliances and digital consumer electronics sold in Japan, we measure the *pricing patterns* of how the price of a product changes over its product life-cycle. In addition, we measure the *quality improvement ratio* (hereinafter called QIR) in order to see how much the quality growth of a new product over an old one can explain their price difference. In the empirical analysis, we will use large data sets of as much as about 5.6 million cases which are stored by *Kakaku.com*, the most popular internet price comparison site in Japan.

This paper is organized as follows. In section II, we introduce preceding studies and discussions on quality adjustment of price indexes and then we deduce some expected characteristics of the pricing patterns and the QIR mathematically, based on the price setting behavior of firms which is widely observed. In section III, we conduct hedonic regressions with time dummies to large granular data sets obtained from *Kakaku.com* and present the topical results of the analysis. Finally, in section IV, we review key research findings obtained from the empirical analysis and consider implications for the existing quality adjustment methods.

II. Literature Survey and Discussions

(1) The Boskin Commission Report

As stated in the previous section, the price difference between a new product and an old one has to be decomposed into the contributions of quality growth and pure price increase in order to produce the price index. The issue on how this decomposition should be done in practice has been discussed as one of the most important problems concerning quality adjustment among practitioners and researchers of price statistics.

The Boskin Commission Report is a representative example for such discussions (see Advisory Commission to Study the Consumer Price Index (1996)). The report, published in 1996, sorted out the issues on the measurement of the price index from the 1980s to the first half of the 1990s. The report provoked lively discussions in the U.S. on measurement errors arising from the applied methods of quality adjustment. The report criticized that Bureau of Labor Statistics (BLS), which is responsible for producing the price index in the U.S., often compares the price difference between new products and old products directly,[1] and therefore, underestimates the contribution from quality improvement. Against such criticism, BLS itself and some economists (e.g., Triplett (1997), Moulton and Moses (1997)) responded that if we link new products and old products in a way that the price index is not be changed when firms are raising pure prices in time with the launch of new products,[2] we

[1] This approach (so-called direct comparison method) is appropriate when the reported price difference between a new product and an old one reflects pure price increase.

[2] This approach (so-called overlap method) is appropriate when the price difference between a new product and an old one, simultaneously available for a certain period of time, is stable and represents pure quality difference of the two products.

may overestimate those contribution from quality improvements.[3]

By quantitatively evaluating the presumption of these discussions, this paper aims to provide useful knowledge to practitioners and researchers who are interested in the preparation of the price index and the price setting behavior adopted by firms.

(2) Price Setting Behavior of Firms

In the first place, why firms have a tendency to increase constant-quality prices (quality-adjusted prices to control price contributions stemming from quality difference) when launching new products? Besides, why prices of products tend to be decreased gradually over the life cycle? In this subsection, we will briefly survey the literature on such price setting behavior of firms in non-technical terms.

The firms' behavior to raise prices at the time of launching new products and the patterns of prices following the decreasing trend after the launch can be interpreted as a consequence of inter-temporal price discrimination. Among the purchasers of durable consumer goods, there are a certain number of consumers who are inelastic to the price (so-called *Early Adopters*) because they would like to buy a new product immediately after its launch even if it is considerably expensive. Having in mind the existence of such consumers, firms trying to maximize their profits have an incentive to set the price of a new product higher than the one appropriate for its quality. Afterwards, as price-inelastic consumers have gone out of the market either because they have purchased the new product in mind or passed on it, subsequently, in order to attract price-elastic consumers whose purchasing decision is based on the balance of quality and price (so-called *Majority*), firms gradually reduce the price in line with the consumers' willingness to pay for it. Reflecting such price setting behavior adopted by firms, we can observe the pricing patterns following the decreasing trend over the product life-cycle for many durable consumer goods which have room for differentiating products.

Such behavior of firms has been empirically known for a long time, and numerous

[3] There has also been a criticism that the method proposed by the Report to estimate errors in quality adjustment is too subjective. In response to it, Gordon (1997), one of the authors of the report presented a counterargument "it is better to be imprecisely right than precisely wrong," incurring exchanges of opinions strongly reflecting the philosophy on quality adjustment.

theoretical models have been devised to explain the behavior. In the mid-2000s and after, moreover, with the improved availability of granular data, empirical studies started in earnest in this area, prompting lively discussions of the implication of these studies on the price index. Nonetheless, common understanding has not been reached yet.

For instance, Aizcorbe, Bridgman, and Nalewaik (2010) has confirmed that the U.S. consumers with relatively high income who appear to be inelastic to the price are quicker in purchasing new models of cars than those with low income. This observation suggests that firms have the corresponding incentives to increase prices at the time of launching new products. If such incentives are not taken into consideration when producing the price index, quality growth could be overestimated (or the price index could be biased downward) by regarding all of the price difference between new products and old products as reflecting quality improvements.[4] Gowrisankaran and Rysman (2012) has shown similar results by observing firm's price setting behavior in the U.S. camcorders market. On the other hand, by quantitatively analyze the product life-cycle of many durable consumer goods, Bils (2009) claims to have found that on average most price differences between new products and old products are due to quality growth, and criticizes that BLS is possibly rather underestimating such quality improvement (or the price index could be biased upward).

As such, even the most recent research results have not yet solved the controversy on the degree of errors in the price index caused by the firms' behavior of setting prices.

(3) Characteristics of Pricing Patterns and Quality Growth

Given the price setting behavior of firms outlined in the previous subsection, here we explain the expected outcome of the empirical analysis which will be performed later. Specifically, we first show the expected characteristics of the pricing patterns, which show the general tendency of price changes through the product life-cycle. In addition, we define the QIR, which represents the ratio of the quality contribution over the total price difference between a new product and an old one, and the dynamics of the distribution of the QIR is mathematically characterized.

[4] In addition, Melser and Syed (2014) has pointed out that pricing patterns of non-durable consumer goods tend to be sloping down and such patterns could create the potential for a downward bias of price indexes.

When firms increase the constant-quality price of a new product at the time of product turnover as a consequence of inter-temporal price discrimination, the price is likely to follow the decreasing trend over the product life-cycle after its launch. In particular, since the demand of price-inelastic consumers for a new product is limited and saturates immediately after its launch, the product price is likely to fall rapidly at first. With the elapse of time, the pace of the price fall becomes more and more gradual, suggesting the fade-out of the effect of the initial increase in constant-quality price.

Suppose the price of product i at the timing of the product launch τ_i means p_{i,τ_i} and let p_{i,τ_i} to be normalized to one without loss of generality. Similarly, the price of product i at τ weeks after its launch represents $p_{i,\tau_i+\tau}$. Then, the average pricing pattern of overall products could be characterized as monotonically decreasing concave function.

$$p_{i,\tau_i+\tau|\tau=0} = 1, \quad \frac{\partial \mathrm{E}(p_\tau)}{\partial \tau} < 0, \quad \frac{\partial^2 \mathrm{E}(p_\tau)}{\partial \tau^2} > 0 \tag{1}$$

On the other hand, if we look at the variance of prices among products, since the pace of the price fall differs even among the products belonging to the same category, the variance of product prices is likely to increase with the passing of the time after the launch of products.[5]

$$\mathrm{Var}\left(p_{\tau|\tau=0}\right) = 0, \quad \frac{\partial \mathrm{Var}(p_\tau)}{\partial \tau} > 0 \tag{2}$$

Next, based on the above-mentioned inequalities (1) and (2), we assume the situation in which a new product and an old one are sold in parallel (see Figure 1). The QIR between an old product (product i) and a new one (product j) at τ weeks after the launch of the new product is defined as follows.

$$\mu_\tau^{i,j} \equiv \frac{\Gamma^{i,j}}{p_{j,\tau_j+\tau} - p_{i,\tau_j+\tau}} = \frac{\Gamma^{i,j}}{\Delta_\tau^{i,j}} \tag{3}$$

Here $\Gamma^{i,j}$ means the quality difference and $\Delta_\tau^{i,j}$ means the price difference between the new product and the old product at τ weeks after the launch of the former, respectively. Based on the definitional equation (3), the expected value and variance of the QIR could be approximated as follows (see Mathematical Appendix 1 for details).

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[5] Mizuno and Watanabe (2010) has investigated fluctuations in prices of some specific products by using tick-by-tick data obtained from *Kakaku.com*, and concluded that the process of the observed prices corresponds to close to a random walk.

$$\mathrm{E}(\mu_\tau) = \mathrm{E}\left(\frac{\Gamma}{\Delta_\tau}\right) \approx \frac{\mathrm{E}(\Gamma)}{\mathrm{E}(\Delta_\tau)} + \frac{\mathrm{E}(\Gamma)}{\mathrm{E}(\Delta_\tau)^3}\mathrm{Var}(\Delta_\tau) - \frac{\mathrm{Cov}(\Gamma, \Delta_\tau)}{\mathrm{E}(\Delta_\tau)^2}$$

$$\mathrm{Var}(\mu_\tau) = \mathrm{Var}\left(\frac{\Gamma}{\Delta_\tau}\right) \approx \left(\frac{\mathrm{E}(\Gamma)}{\mathrm{E}(\Delta_\tau)}\right)^2 \left(\frac{\mathrm{Var}(\Gamma)}{\mathrm{E}(\Gamma)^2} + \frac{\mathrm{Var}(\Delta_\tau)}{\mathrm{E}(\Delta_\tau)^2} - \frac{2\mathrm{Cov}(\Gamma, \Delta_\tau)}{\mathrm{E}(\Gamma)\mathrm{E}(\Delta_\tau)}\right)$$

Then, if we differentiate the expected value and variance of the QIR with respect to time variable τ, we obtain the following inequalities (see Mathematical Appendix 2 for details):

$$\frac{\partial \mathrm{E}(\mu_\tau)}{\partial \tau} > 0, \quad \frac{\partial \mathrm{Var}(\mu_\tau)}{\partial \tau} > 0 \tag{4}$$

For convenience, if the QIR is assumed to follow a unimodal and symmetric distribution, as shown in inequalities (4), the mean of the distribution is expected to shift to the right while the tail of the distribution becomes wider with the elapse of time (see Figure 2).

Taking into consideration the characteristics of the pricing patterns and the shapes of the QIR distribution, in the next section, we will carry out the empirical analysis based on huge volume of granular data collected from *Kakaku.com*, and confirm whether such patterns and shapes are observed from the actual data for each commodity.

III. Empirical Analysis

(1) Overview

Given the above-mentioned discussions and literature survey on quality adjustment as well as the results of mathematical deductions, it is expected that the pricing patterns of products follow a decreasing slope. In addition, the QIR is expected not to take extreme values such as 0%—which is equivalent to regarding all the price difference between new products and old products as the constant-quality price increase—or 100%—which is equivalent to regarding all the price difference as the quality improvement part—but rather some values in between them (e.g., 50%).

In verifying such expectations, we perform the empirical analysis following the procedures below. First, we will (i) outline the data sets used in the analysis, and (ii) estimate the hedonic functions using product prices data as explained variable, while using product quality characteristics data (specifications data), dummy for the number of elapsed weeks from the launch date, and dummy for the timing to control exogenous macroeconomic shocks as explanatory variables. Then (iii) we will sort out for each commodity the resulting facts on the average pricing patterns. Next, (iv) we will explain the criteria to select "matched pairs" of products which are regarded as the genuine pair at product turnover. Lastly, (v) we will calculate the quality difference between new products and old products for each of matched pair. And we will measure the QIR by dividing the quality difference by the price difference of the same pair and examine the characteristics of the distribution.

(2) Data Sets

In order to conduct the above-mentioned analysis, the data sets need to include consistent and comprehensive information on various specifications of products, which are necessary to develop a high quality estimation model, as well as the information on frequently revised prices, which allows us to accurately capture the price transitions. In this paper, given these conditions, we use the data of *Kakaku.com* which provides price-comparison information for consumers.[6] Specifically, we obtained (i) the data from the website of *Kakaku.com* on product specifications of both home electrical appliances and digital consumer electronics which were registered at the website between December 2012 and December 2015 (i.e., they were likely to be newly launched during the corresponding period)[7] and (ii) the data from *Kakaku.com Trend Search Enterprise Edition*, a marketing support service operated by *Kakaku.com, Inc.*, on the average price of individual products with weekly frequency from December 2013 to December 2015;[8] and by integrating both, we developed the unbalanced panel data sets which are suited for our analysis needs.[9]

The data sets consist of eight commodities of home electrical appliances (air conditioners, refrigerators and freezers, washers and dryers, rice cookers, vacuum cleaners, microwaves,

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6 It can be pointed out as the merits of using the said data that, according to several indicators, the data source is the most popular price comparison website in Japan. In addition, the basic characteristics of the data of *Kakaku.com* have been well-understood thanks to the previous studies such as Mizuno and Watanabe (2010), Mizuno, Nirei and Watanabe (2010), Nakano and Nishimura (2013), etc.

7 In the specifications data, for the products which can be seen as the same products except for the element of color, only one product with a major color was used for the analysis.

8 In order to exclude the direct impact of the consumption tax hike in April 2014, original price data with inclusive of tax were converted into prices excluding tax.

9 We also conducted the empirical analysis by using the cheapest-price data instead of the average price data, but the key results of this paper are unchanged.

hair dryers and curling irons, air purifiers) and twelve commodities of digital consumer electronics (GPS navigations, external hard drives, LCD TVs, LCD monitors, printers, Blu-ray and DVD recorders, headphones, camcorders, laptops, desktops, point-and-shoot cameras, DSLR and mirrorless cameras). The number of products included in the above data sets is about 4,500, while the size of panel data multiplying the number of products and the number of data periods corresponding to each product is about 150,000. Moreover, the so-called volume of total data—which are obtained by multiplying the size of panel data and the number of specification data corresponding to each product—is huge at over about 5.6 million.

(3) Estimation of Hedonic Functions

In the empirical analysis, following the insights of the previous studies such as Haan (2004), Triplett (2006), and Nakano and Nishimura (2013), we will estimate the following hedonic functions which incorporate dummy variables to control the elapse of time from the launch of products so that we can capture the effect of price transition through the life-cycle of products.[10]

$$\ln(p_{i,t}) = \alpha + \sum_{k} \beta_k X_{i,k} + \sum_{\tau} \gamma_\tau D_t(\tau_i + \tau) + \sum_{\tau} \delta_\tau D_t(\tau) + \varepsilon_{i,t} \qquad (5)$$

$$\text{where } D_t(T) = \begin{cases} 1 & (\text{if } t = T) \\ 0 & (\text{if } t \neq T) \end{cases}$$

In this equation, $p_{i,t}$ represents price of product i at time t, while $X_{i,k}$ shows kth specification of product i. $D_t(\tau_i + \tau)$ and $D_t(\tau)$ mean the dummy variable to control the number of elapsed weeks from the launch of each product at τ_i, and the dummy variable to control macroeconomic shocks in each quarter during the data period, respectively. $\varepsilon_{i,t}$ is an unobserved random disturbance term. For the number of elapsed weeks dummy variable, we use the total elapsed days from the launch date of each product and divide it by 7. Moreover, for the time dummy variable, orthogonality with the number of elapsed weeks dummy was secured by identifying the quarter which includes the point of time in accordance with the calendar date.

[10] Generally speaking, a hedonic function is used to calculate the part of the price changes that correspond to the change in quality at product turnover.

Specifications of each product include both of those which are expressed as continuous values and those as dummies. Placing importance on securing the comparability among commodities, this paper will use the common form of functions for all commodities in terms of formulation of the data. In this vein, we have conducted regressions specified in both semi- and double-logarithmic forms and we concluded that the semi-logarithmic form was superior in terms of log-likelihood values. We therefore have adopted the semi-logarithmic form (as represented in equation (5)), which is also recommended by ILO (2004).

In the equation (5), explanatory variables are clustered in the direction of cross-section by the manufacturers dummy, which is one of the key components of product specifications, while they are clustered in the direction of time-series by the time dummy for quarters. Accordingly, in the analysis of this paper, all the data is pooled, and then the standard LSDV (Least Square Dummy Variables) estimation has been applied.[11] To ensure robustness of estimation against the presence of serial correlation and heteroskedasticity in the disturbance term, White period estimates have been applied for calculating robust standard errors (see Arellano (1987)).

As a result of an initial estimation, we eliminate the specifications which destabilize the estimation owing to multicollinearity or which do not satisfy either five percent significance or sign condition. We then repeat the estimation and elimination of further variables if necessary, until we obtain stable and significant results.

The results of hedonic estimations by commodities are summarized in Tables 1 to 10. The estimated coefficients of elapsed week dummy variables show a significant result for almost all commodities, excluding a certain period of time immediately after the launch of products when, by its definition, the estimated value of coefficients is expected to is close to zero. On the whole, the results of estimation in this paper can be said to have shown a quite nice performance.

[11] The products which lacked the information on specifications were excluded from the estimation. However, if there were too many products which lacked a certain specification, the corresponding specification was conversely excluded from the data sets, from the viewpoint of securing sufficient amount of data for the estimation.

(4) Measurement of Pricing Patterns

Next, we measure the average pricing patterns of products by commodities. Since the quality of each product is constant over its life cycle, and changes in macroeconomic conditions are controlled by the time dummy for quarters, changes in the average prices of products with the elapse of time are expressed as changes in the estimated value of coefficients of elapsed week dummy variables. In order to give a picture of pricing pattern of each commodity, we plot the coefficient estimates of week dummy variables with exponential transformation ($\exp(\hat{\gamma})$) along with the elapse of time after the launch of the product (see Figure 3). Observation of the pricing patterns reveals that the price of products has a tendency to decrease as time proceeds from the launch for almost all commodities except one (washers and hair dryers) though the degree of the price decrease varies somewhat among commodities. That is to say, at product turnover, firms appear to set the price of a new product higher than is justified by the quality improvement, which is constant through the life-cycle of the product; they intend to increase the constant-quality price, whose effect is likely to fall off with the elapse of time.

Moreover, for most commodities, we also observed a tendency that the pace of decrease in product prices becomes moderate as time proceeds. This observation is interpreted to reflect the firms' price setting behavior that, after the initially-set higher price, targeting a small number of price-inelastic consumers, rapidly decreases due to the saturation of demand by those consumers, firms try to appeal to more consumers by gradually decreasing the price. In the meantime, the variance (standard deviation) of product prices within the same category of commodity gradually increases with the elapse of time after the launch.

Observation on the pricing patterns of each commodity reveals that, generally speaking, the pure price increase of home electrical appliances is somewhat larger than that of digital consumer electronics, while the pace of price decrease of home electrical appliances also tends to be faster. Looking more in detail, while for the so-called "white goods" (major home electric appliances such as refrigerators and freezers, rice cookers, vacuum cleaners, microwaves), the initial drop of the price is clear, the price of digital consumer electronics does not drop as clearly as white goods.

Such a difference is likely to reflect the perspectives of consumers when they evaluate white goods and digital consumer electronics. Regarding white goods, since consumers tend to value more at other elements than quantifiable quality (e.g., design of products and the product image incurred by advertising media among others), individual products can be differentiated more easily, and the price competition over quantifiable quality tends to be more lenient than digital consumer electronics. As a result, a relatively large increase in constant-quality price can be made at the time of launching a new product, and afterwards it falls off substantially as time proceeds.

On the other hand, for digital consumer electronics (such as external hard drives, LCD monitors, printers, laptops, desktops), since consumers have a relatively strong tendency to evaluate products by paying attention to the quantifiable quality, there is little room to differentiate products in the aspects other than quality. Reflecting such a difference in their playing fields, for digital consumer electronics, while the price can be raised as much as the difference in quality at the time of launching a new product, a substantial increase in constant-quality price beyond that is not easy, resulting in a small pure price increase as a whole. As a result, it can be interpreted that the part of the constant-quality price increase, which tends to fall off with the elapse of time, is also smaller, and therefore, the price of products does not fall so much.[12]

(5) Selection of Matched Pairs of Products

The pricing patterns measured in the previous subsection show the average life cycle of one product. In order to verify whether the above-mentioned interpretation of the pricing patterns is appropriate or not from another perspective, it is useful to understand how much constant-quality price increase is made at product turnover. In other words, we would like to characterize the QIR, or how much the quality improvement of a new product accounts for the price difference between new products and old products when launching the former.

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[12] The hedonic function, which provides the basis for the analysis in this paper, can be regarded as the envelop curve of consumers' bid function concerning the specifications of each product when the distributions of preference and income are given. Considering such theoretical interpretation, the downward-sloping pricing patterns can also be interpreted as expressing the relationship that as durable consumer goods become obsolete from the perspectives of consumers with the elapse of time, the marginal utility to be gained from it diminishes. In other words, the difference in the shapes of price patterns can be seen as reflecting the difference in the tempo for products to become obsolete (based on the subjective evaluation of consumers).

In order to measure the QIR between new products and old products, it is an important issue how the combinations of new products and old products are selected. Accordingly, here we explain the method for selecting the matched pairs of new products and old products, which is the basis for measuring the QIR.

If we try to select the pairs of a new product and an old one strictly, we need to accurately understand each manufacturer and the line-up of each product, judge and identify each time which existing line-up the launched new product should be matched to. However, only by using the objective information such as the model names of products and specifications, it is not easy to identify whether a new product belongs to any of the existing line-ups, leaving no other way but to rely on subjective judgment in the end. Moreover, some manufacturers change the product line-up upon the launch of a new product; and therefore, there are many cases in which it is not appropriate in itself to judge, based on the line-up before the launch of a new product, which old product the new one is succeeding to.

Accordingly, in this paper, we place more importance on eliminating the arbitrariness as much as possible in selecting product pairs by defining the matched pairs of new products and old products broadly as those satisfying the following selection criteria:[13]

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[13] Based on these criteria, it is impossible to eliminate pairs of new products and old products which belong to different line-ups (e.g., a pair of "low-end old model" and "high-end new model"). Of course, there is trade-off between securing the objectivity of the selection method and the appropriateness of selection results, either of which should be placed emphasis on a case-by-case basis, if the objectivity of selection method is given importance in selecting the product pairs, there is a concern about possible bias to the analysis results.

In order to eliminate such a concern, we paid attention to the following two additional criteria. The first criterion takes advantage of the tendency that the quality difference between a new product and an old one belonging to the same line-up is relatively small. The second criterion is about the model names of products, which tend to be substantially different for the pair of products belonging to different line-ups. We conducted analysis which excluded the pairs violating each of these two criteria (see Appendix). However, to state the conclusion in advance, the conclusions differ very little regardless of which approach is used, generally confirming the robustness of the analysis results in this paper.

Selection Criteria of Matched Pairs of New Products and Old Products

1. The launch (registered) date of a new product is later than that of the old product
2. New products and old products are made by the same manufacturer
3. The price of a new product on the launch date is higher than that of the old product on the same day
4. The quality of the new product is better than that of the old product

(6) Measurement of Quality Growth

Based on the matched pairs of new products and old products selected in accordance with the above conditions, we measure the QIR of individual pairs, and examine the shapes of the QIR distributions. The QIR $\mu_{\tau}^{i,j}$ could be defined as follows:

$$\mu_{\tau}^{i,j} \equiv \frac{\sum_{k} \beta_k \left(X_{j,k} - X_{i,k}\right)}{\ln\left(p_{j,\tau_j+\tau}\right) - \ln\left(p_{i,\tau_j+\tau}\right)} \qquad (6)$$

We calculate the QIR for each product pairs and demonstrate their histogram by the continuous function.

Figure 4 expresses the distributions of the QIR for the whole commodities, in order to show the overall picture of the analysis results. As the shape of distributions is likely to change with the elapse of time, the distributions are depicted for three points in time: the point immediately after the launch of a new product (at the 1st week); one month later (at the 5th week); and three months later (at the 13th week).[14]

Looking at the distribution of the QIR, it is a unimodal distribution slightly fat-tailed to the right. Regarding the mode value immediately after the launch of a new product, digital consumer electronics have slightly higher values (about 0.6-0.7) than home electrical appliances (about 0.5-0.6). As stated in subsection (4) of this section, this reflects the difference in the perspectives of consumers when they evaluate white goods and digital

[14] About three months after the launch of a new product, the pace of the decrease in price becomes moderate, and the change in the shape of distribution of the QIR becomes very small. Accordingly, Figures 4, 5 and Appendix depicted the distribution only up to three months from the launch, discarding the changes thereafter.

consumer electronics: it suggests that the effect on the price of the elements other than the quantifiable quality—such as the product design and/or product image—is relatively small for digital consumer electronics, and therefore raising constant-quality price is difficult. Moreover, there is a tendency that the distribution of the QIR gradually shifts to the right and its right tail becomes fatter as time proceeds. This shows that the part of the pure price increase fades out with the elapse of time, and this fadeout is accompanied with increased variance of the QIR for a certain period of time.

However, it is interesting that the initial difference in shapes of the QIR distributions for home electrical appliances and digital consumer electronics gradually decrease as time passes by, and in three months the shape becomes relatively similar. A possible explanation for this observation is that the initial difference in shapes of the QIR distributions, which reflects the different degree of pure price increase at the launch and is strongly influenced by the characteristics of each commodity, gradually decreases with the elapse of time and thus eventually becomes small. Although such inference does not have a sufficient theoretical basis, it is a thought-provoking phenomenon from the perspective of producing the price index in practice; and therefore, we would like to make it an issue for future research.

Figure 5 expresses the distribution of the QIR for each commodity immediately after the launch of a new product, one month later, and three months later. Looking at this, we can see that the facts which were observed for home electrical appliances and digital consumer electronics are similarly observed for almost all commodities.

IV. Concluding Remarks

(1) Key Findings

Regarding the price difference between a product and its successor, a classic yet new issue in producing the price index is whether it corresponds to the quality growth of the new product over the old one or to the pure price increase as a consequence of the firm’s price setting behavior intended to ensure the profitability. It appears to be appropriate to think that in reality the effects of both are reflected in the price difference, but there had been no consensus about their respective degrees of impact has yet to be reached either in practice or in academics.

Under these circumstances, we performed the empirical analysis in this paper using the large-scale data sets of *Kakaku.com*, and measured for each commodity the average tendency in price transition through the life-cycle of durable consumer goods as well as the ratios due to the quality difference out of the price difference between new products and old products.

As a result, it turned out that (i) increases in constant-quality price, intended to ensure the profitability when launching a new product; are widely observed both for home electrical appliances and digital consumer electronics; (ii) the pace of price decrease tends to become moderate with the elapse of time; and (iii) home electrical appliances has a somewhat larger degree of pure price increase at the launch and a somewhat faster pace of price fall afterwards, compared to digital consumer electronics. Moreover, it was observed that (iv) the QIR, which shows the ratio of the price difference between new products and old products due to the difference in quality, depicts a unimodal distribution fat-tailed slightly to the right for both home electrical appliances and digital consumer electronics, and (v) the mode value of the distribution measured immediately after the launch of a new product indicates about 0.5-0.6 for home electrical appliances, and about 0.6-0.7 for digital consumer electronics, and therefore, digital consumer electronics have somewhat higher QIR than home electrical appliances (alternatively, the ratios of constant-quality price increase are somewhat lower for digital consumer electronics than for home electrical appliances).

As far as the authors are aware, there has been little empirical analysis conducted regardless in Japan or abroad, focusing on the detailed price transitions of individual products as was done in this paper. The analysis results of this paper are likely to be of interest not only to practitioners of price statistics but also to researchers who are broadly interested in the price setting behavior of firms.

However, it should be borne in mind that the estimation period of this analysis only ranges from December 2013 to December 2015, due to the limitation of data availability. It may be the case that the stability of macroeconomic conditions during this period in Japan has partly contributed to the stability of the estimation in this paper.[15] In other words, if we are

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[15] In this paper, products prices have been converted into prices excluding consumption tax, and exogenous macroeconomic shocks which affect every product simultaneously have been absorbed

faced with macroeconomic shocks such as large-scale natural disasters and turmoil in international financial markets, as well as ground-breaking innovations in the future, it cannot be denied that the reality may deviate from this paper's analysis results, partly owing to the limit of the reduced form specification of the model. The pricing patterns and the distributions of the QIR measured by the authors should be seen with some caution, bearing in mind that they may change due to exogenous shocks.

Moreover, the prices at the end of products' life-cycle sometimes show unstable movements, such as sudden jumps up and down, mainly because of the decrease in the stores which deal with them. Accordingly, this paper captured the life cycle of each product only for the period generally within one year from the launch date. While we were able to obtain stable estimation results by taking such measures, it should be noted that we did not analyze in this paper peculiar price transitions, perhaps due to the disposition of old models.

(2) Implications for Quality Adjustment Methods

As stated in earlier, both the quality growth of new products and pure price increase intended to ensure the profitability have an impact on both of the two extreme views – regarding the quality of the new and old products as totally the same (using direct comparison method), or seeing all the price difference due to the difference in quality (using overlap method) – may be subject to measurement errors in the price index.

While hedonic method is one of the in-between methods, since the method requires a large volume of latest data in order to obtain high precision, it entails substantial difficulties to expand applicable items, given the resource constraints of statistics agencies. As Nair (2004) points out, the application of hedonic method in general remains to be limited to a few products and services; and considering its cost-effectiveness in particular, it will not

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by time dummy variables. Therefore, the rise in consumption tax rate in April 2014 does not have a direct impact on the main analysis results of this paper such as the measurement of pricing patterns and the QIR. When the estimated coefficients of time dummies for the 1st and 2nd quarters of 2014 were compared, the decrease in tax exclusive prices was confirmed towards the 2nd quarter. It suggests that firms may have offered appealing prices to alleviate consumers' sense of burden, in response to the lowered consumer sentiment immediately after the tax hike. However, if firms launch special sales strategies in anticipation for the rise in tax rates, the framework of this paper may not be able to take into consideration its impact.

replace the standard quality adjustment methods in the future.

Under these circumstances, some price statistics agencies have applied a simple quality adjustment method, as a kind of experts judgment, to regard 50% of the price difference between new products and old products as the contribution from quality improvement if hidden pure price increase is suspected along with the quality growth of a new product but its magnitude is not known (so-called *50% rule*). In Netherlands, Hoven (1999) explains the 50% rule has been applied for electrical household appliances and hi-fi equipment if some concealed price increase is assumed. Similarly, as Dalen and Tarassiouk (2013) argues that Statistics Sweden makes the quality adjustment based on the 50% rule for transport equipment excluding cars (motor cycles, caravans, campervans, boats) when no relevant information is available for applying other quality adjustment methods. Based on Hoffmann (1999), the 50% rule was available as the second-best way to conduct the quality adjustment among the Federal Statistical Office of Germany prior to 1997. In the past, Ohta (1977) has proposed to use the 50% rule for the quality adjustment based on the principle of risk minimization under uncertainty where we do not know the qualities of products well.[16]

However, the 50% rule that has been proposed or adopted in the above-mentioned countries is not sufficiently supported either theoretically or in practice. It may even be a rule of thumb, suggesting to statistical agencies a practical policy of minimizing the uncertainties when there is no empirical evidence. On the contrary, the results of this paper support, to some extent as a second-best solution, the appropriateness of the 50% rule,[17] which has so

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[16] In addition, some European countries have adopted the option cost method, based on the similar thinking to the 50% rule. Targeting some durable consumer goods, this refers to the method which regards half of the price for adding the options as the quality difference between new products and old products regarding the functions that were optional for the old product but are standard for the new one. It regards not all but half of the option price as the quality difference because all consumers are not considered to feel the benefit of such standard functions equipped with the new product. The philosophy of this method is similar to the 50% rule in that it applies *a priori* value of 50% to the evaluation of uncertain quality. See Dalen and Tarassiouk (2013) for the case of new car models in Sweden, Ball and Allen (2003) for the case of personal computers in the UK, etc.

[17] While past cases were conscious about the application of the 50% rule for the price level difference between new and old products, the analysis in this paper has calculated the QIR based on the relative price (difference in log-transformed prices) between new and old products in a strict sense. If the relative price is close to one, in other words if there is no substantial disparity between their price levels, the difference in the way of calculation can be ignored.

far lacked the rationale for its application. In other words, the results of this paper would be useful not only for researchers but also for practitioners of price statistics, in that it justifies a quality adjustment method which is easy to adopt even under severe constraints with resources and contributes to improving the precision of the price index.[18]

[18] The Bank of Japan has announced the rebasing of the PPI by updating the base year from 2010 to 2015. Taking that opportunity, the Bank plans to introduce a new quality adjustment method for some items (eight commodities of household electric equipment and ten commodities of information & communications equipment) based on the thinking of the 50% rule for the limited cases where other quality adjustment methods are difficult to apply.

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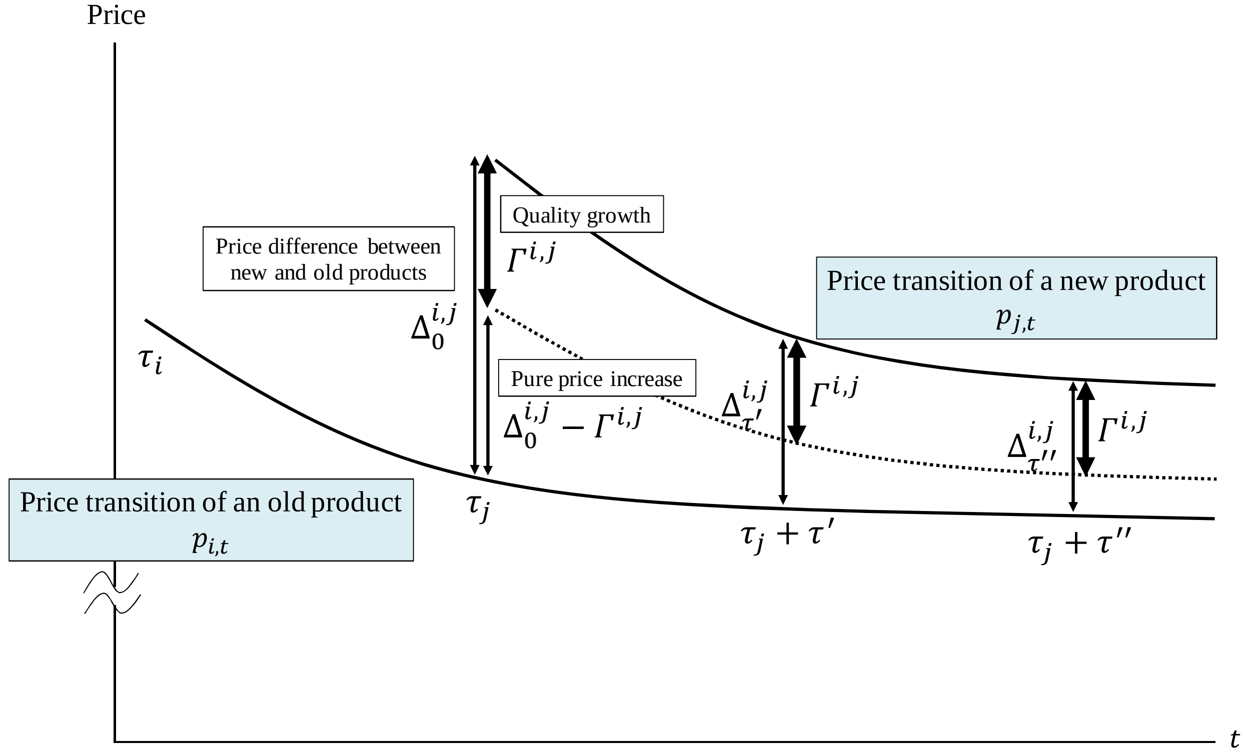
Figure 1

Conceptual Diagram of Quality Growth and Pure Price Increase



*Time *t* in this graph does not indicate a concrete point of time but just represents a virtual concept.

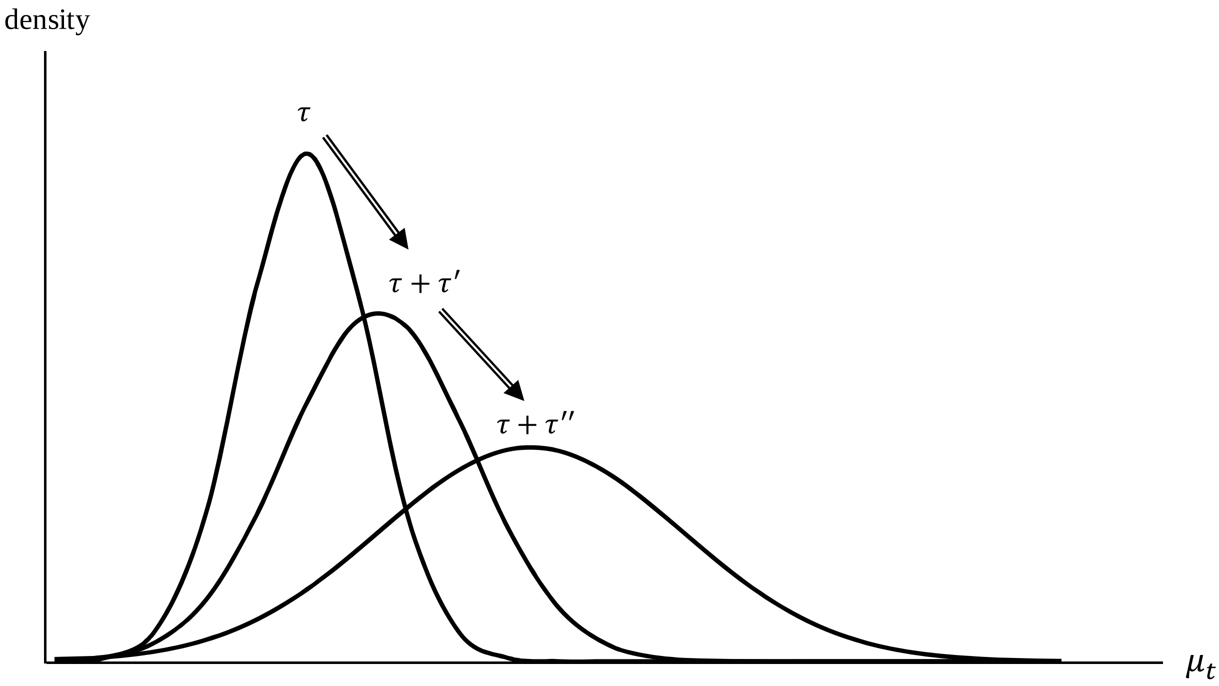
$$
\begin{aligned}
\underbrace{p_{j,t} - p_{i,t}}_{\text{Price difference between new and old products at } t} &= \Delta_{t-\tau_j}^{i,j} \\
&= \underbrace{\Gamma^{i,j}}_{\text{Quality growth (constant as to } t)} + \underbrace{\left(\Delta_{t-\tau_j}^{i,j} - \Gamma^{i,j}\right)}_{\text{Pure price increase at } t}
\end{aligned}
$$

Shrinking of price difference between a new product and an old one with the elapse of time leads to the reduction of the contribution derived from the initial pure price increase, because quality growth is constant as to the time, i.e.,

$$\frac{\partial(p_{j,t} - p_{i,t})}{\partial t} = \frac{\partial \Delta_{t-\tau_j}^{i,j}}{\partial t} < 0$$

Figure 2

Shift in Distribution of Quality Improvement Ratio



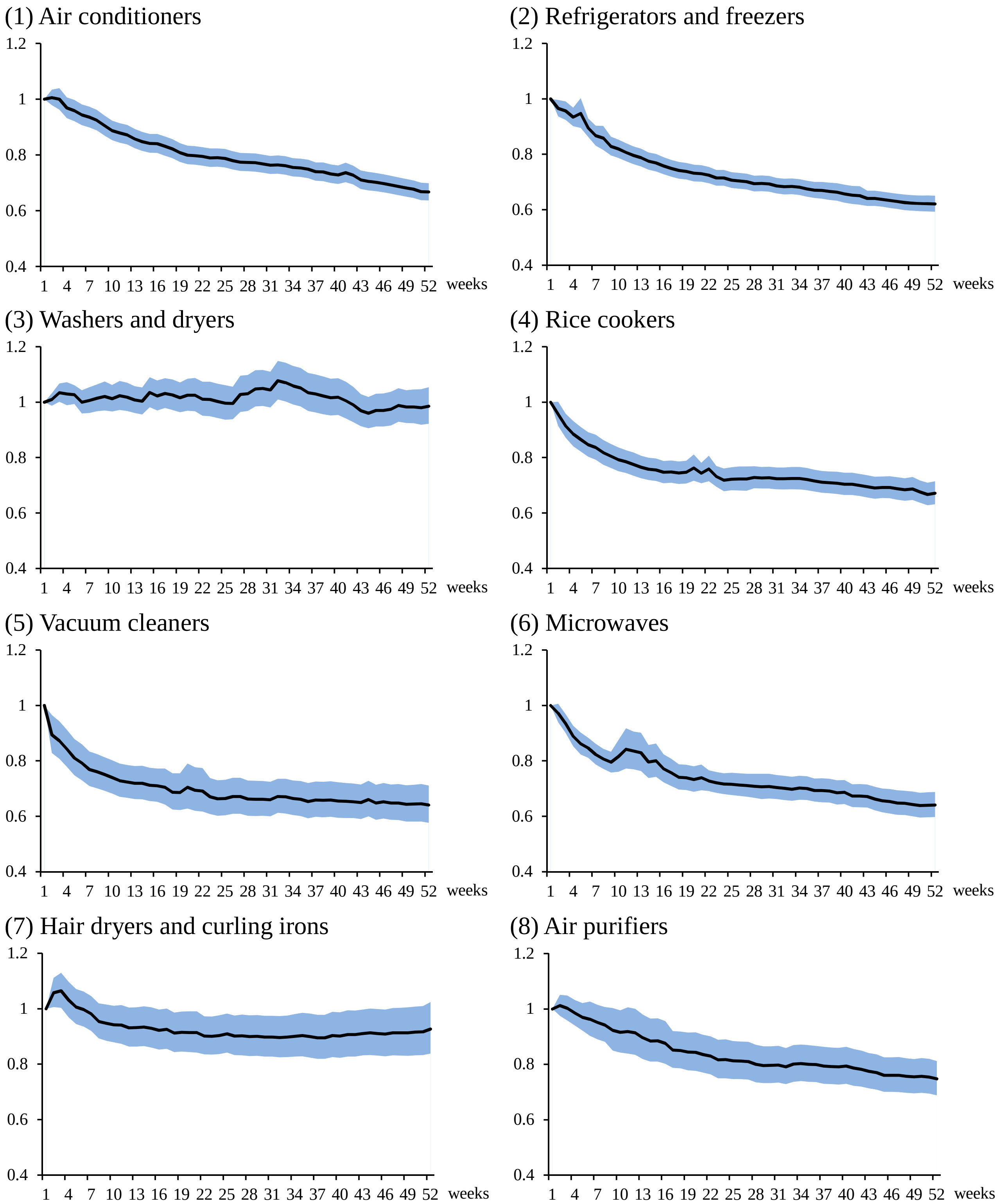
$$\text{Quality Improvement Ratio: } \mu_t^{i,j} = \frac{\Gamma^{i,j}}{\Delta_t^{i,j}}$$

If the quality improvement ratio, QIR, between a new product and an old one ($\mu_t^{i,j}$) is assumed to follow the unimodal and symmetrical distribution, the distribution is expected to shift to the right while the width increases with the elapse of time ($\tau \Rightarrow \tau + \tau' \Rightarrow \tau + \tau''$) under certain conditions, i.e.,

$$\underbrace{\frac{\partial \mathrm{E}(\mu_t)}{\partial t} > 0,}_{\text{Shift to the right of the center of the distribution}} \qquad \underbrace{\frac{\partial \mathrm{Var}(\mu_t)}{\partial t} > 0}_{\text{Widening bottom of the distribution}}$$

Figure 3-1

Pricing Patterns over Product Life-Cycle: Home Electrical Appliances



Note: The scale of a longitudinal axis is adjusted by dividing a price by the price right after the launch of new product. The shaded areas indicate double standard deviation $\pm 2\sigma$.

Figure 3-2

Pricing Patterns over Product Life-Cycle: Digital Consumer Electronics (1)

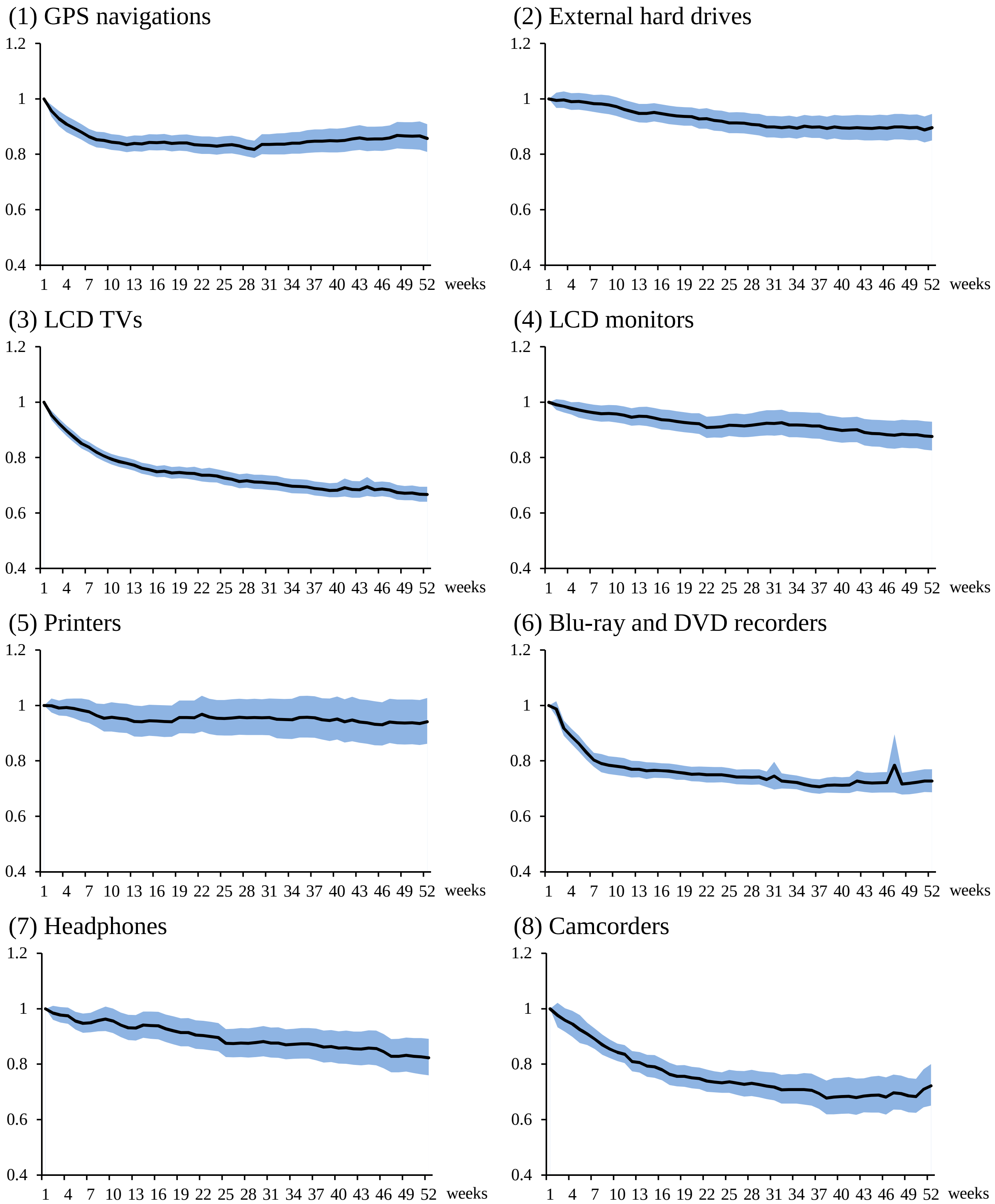


Figure 3-3

Pricing Patterns over Product Life-Cycle: Digital Consumer Electronics (2)

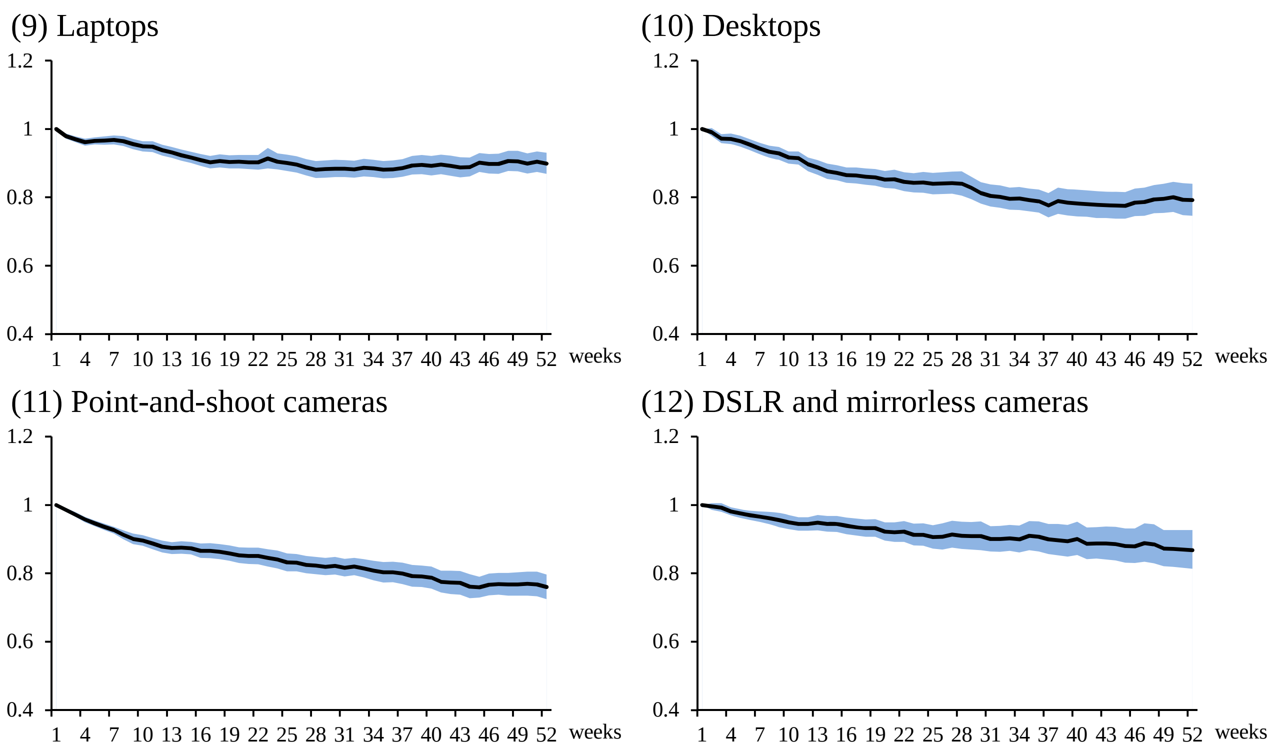
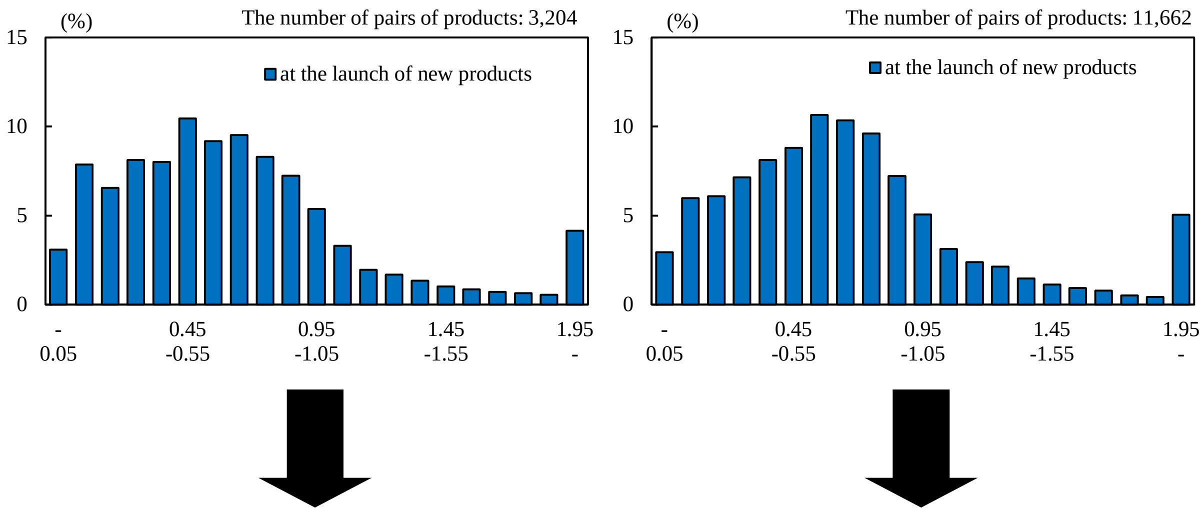


Figure 4

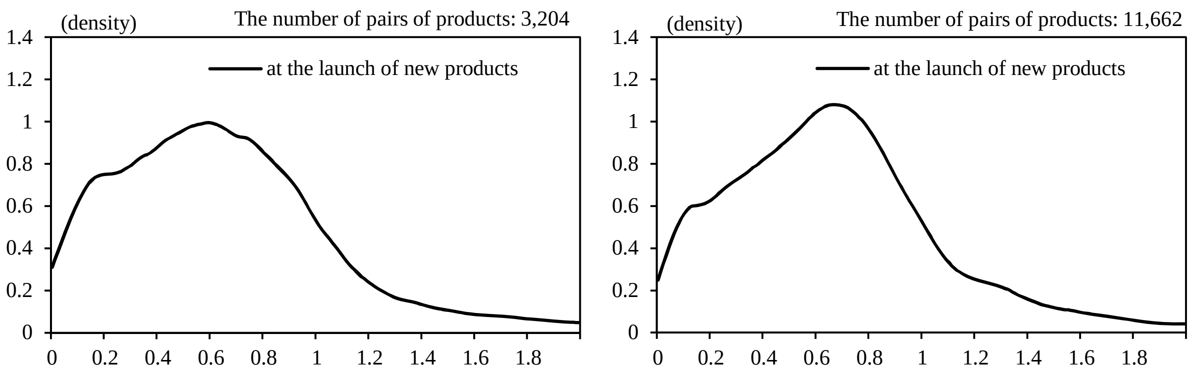
Distribution of Quality Improvement Ratios: Overview

(1) Home electrical appliances (2) Digital consumer electronics

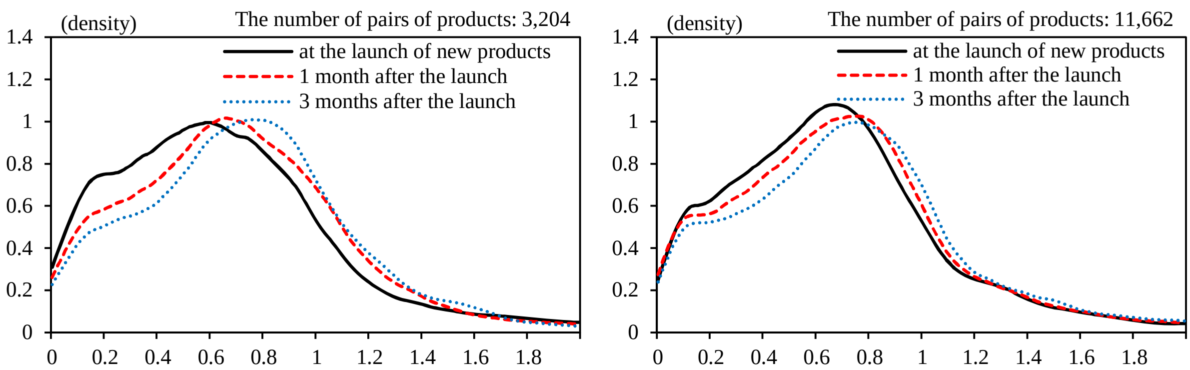
(Description using histogram)



(Approximation using Kernel density graph)



(Shift in distribution of quality improvement ratio)

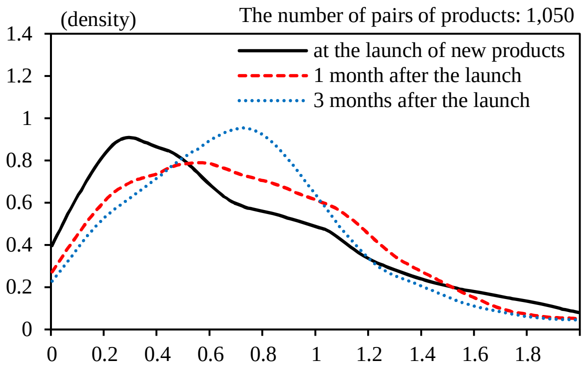


Note: A kernel density estimation enables to approximate a discrete probability distribution by tracing a smooth curve. In these figures, band width is decided by the *Silverman rule* and a kernel function is assumed to be the quadratic *Epanechnikov kernel*. Also, we conduct outlier processing by trimming the upper and lower 1 percent tails of matched pairs of new products and old products.

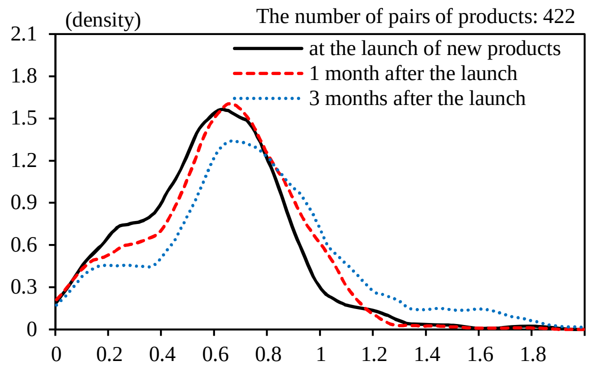
Figure 5-1

Distribution of Quality Improvement Ratios: Home Electrical Appliances

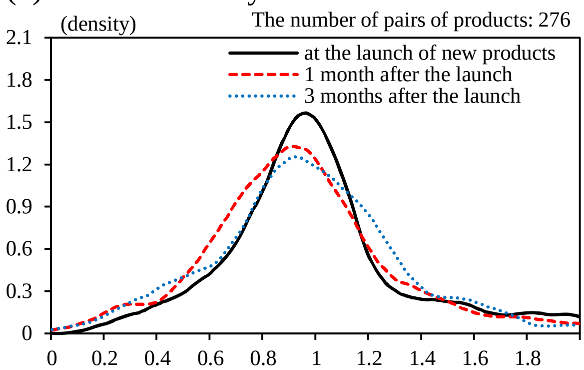
(1) Air conditioners



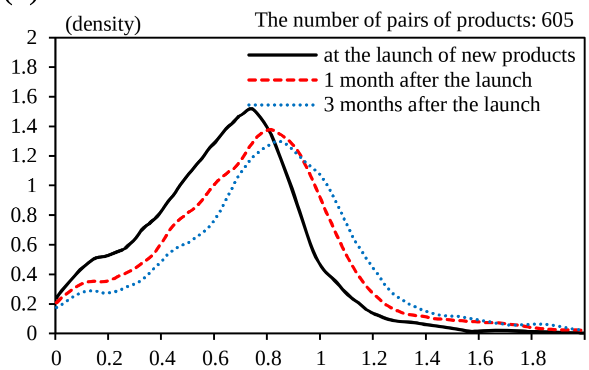
(2) Refrigerators and freezers



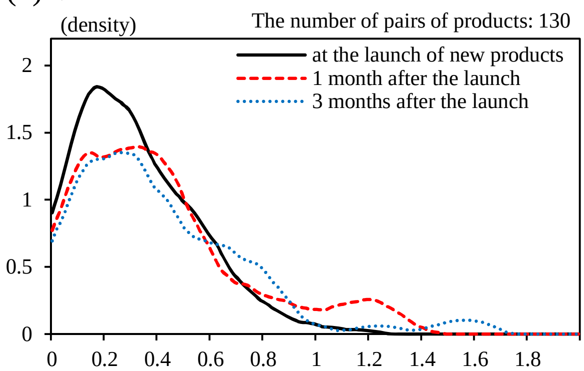
(3) Washers and dryers



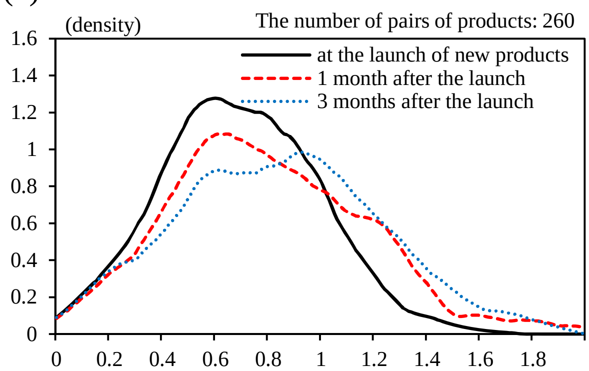
(4) Rice cookers



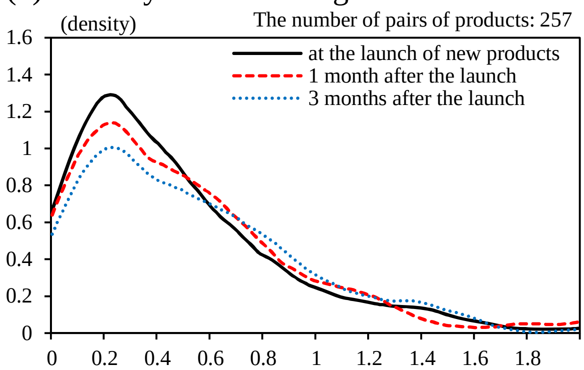
(5) Vacuum cleaners



(6) Microwaves



(7) Hair dryers and curling irons



(8) Air purifiers

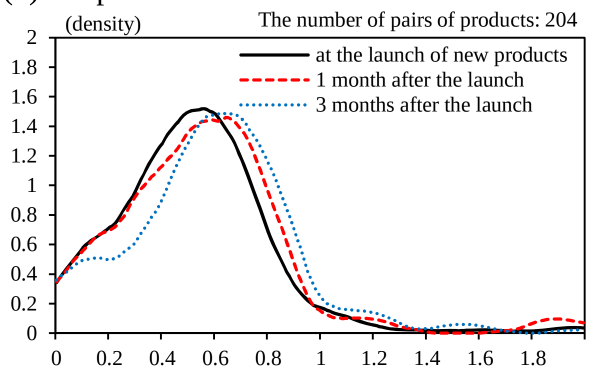
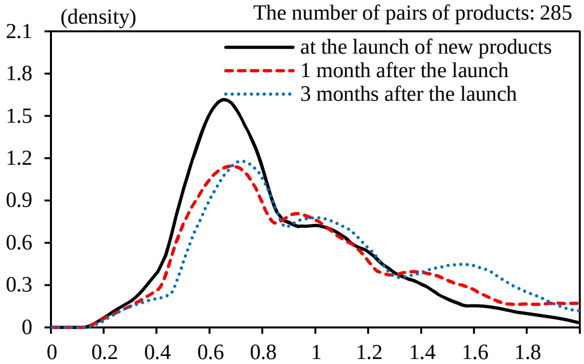


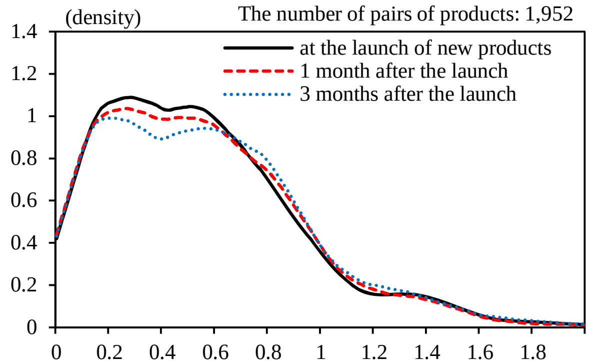
Figure 5-2

Distribution of Quality Improvement Ratios: Digital Consumer Electronics (1)

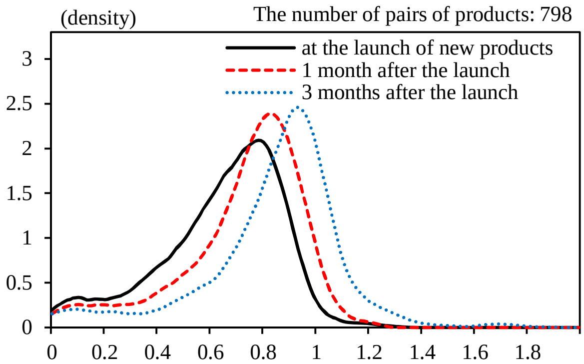
(1) GPS navigations



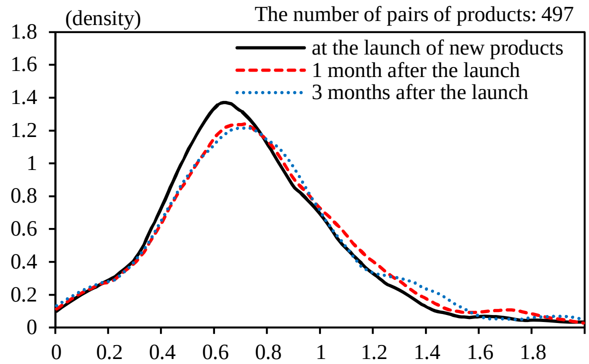
(2) External hard drives



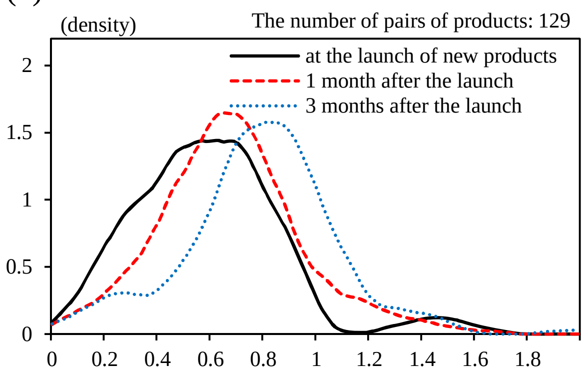
(3) LCD TVs



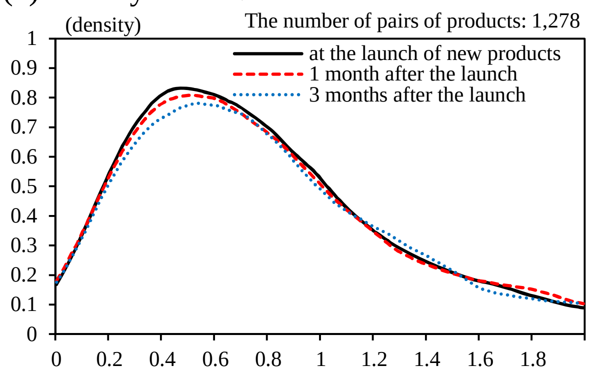
(4) LCD monitors



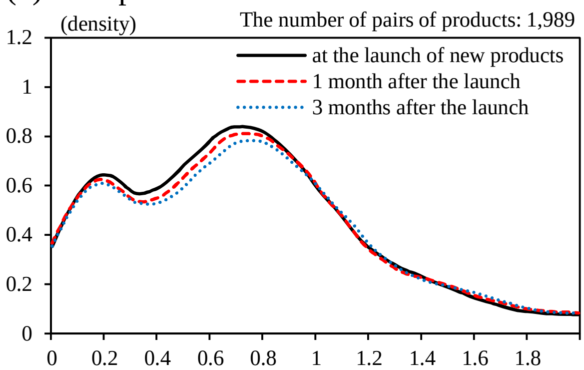
(5) Printers



(6) Blu-ray and DVD recorders



(7) Headphones



(8) Camcorders

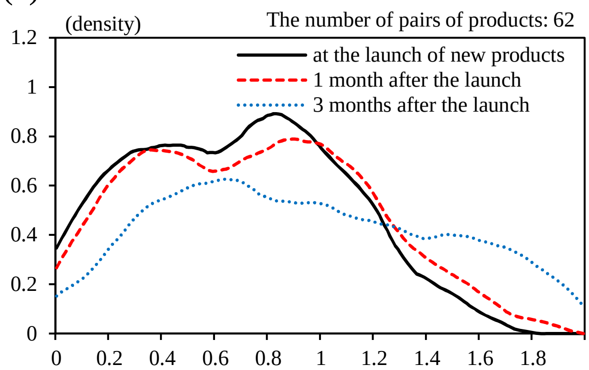
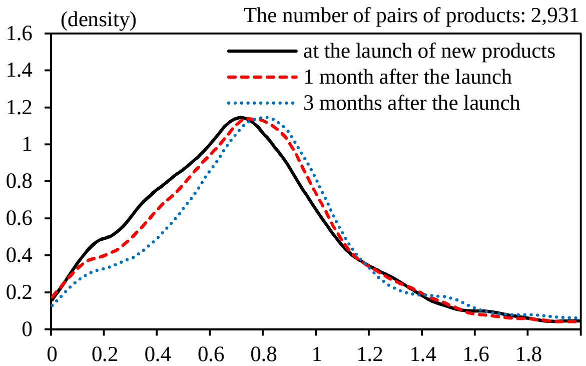


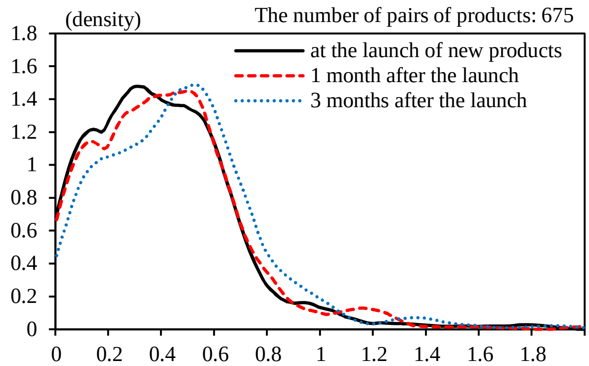
Figure 5-3

Distribution of Quality Improvement Ratios: Digital Consumer Electronics (2)

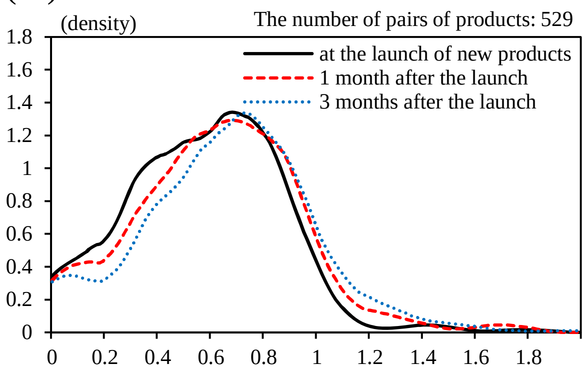
(9) Laptops



(10) Desktops



(11) Point-and-shoot cameras



(12) DSLR and mirrorless cameras

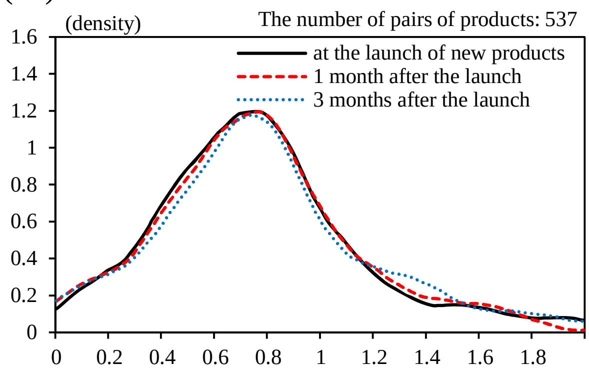


Table 1

Estimation Results of Hedonic Regression: Home Electrical Appliances (1)

(1) Air conditioners

Dependent Variable: log(average price)		
Intercept	10.239 (0.153)	***
Heating Capacity (mat)	0.041 (0.004)	***
Low-temperature Heating Capacity (kW)	0.025 (0.009)	**
Annual Performance Factor	0.072 (0.021)	***
Dummy Variables		
Human Body Sensitive Sensor		
Body	0.076 (0.021)	***
Remote Control	0.262 (0.066)	***
Air Sterilization System	0.107 (0.030)	***
Clothes Dryer System	0.168 (0.024)	***
Automatic Washing System of Filter	0.162 (0.025)	***
Airflow Control System	0.206 (0.052)	***
The refrigerant circuit R32	0.096 (0.028)	***
Reheating Dehumidifier System	0.078 (0.025)	**
Voice Guide System	0.119 (0.026)	***
Manufacturers		
Manufacturer A	0.148 (0.034)	***
Manufacturer B	0.284 (0.040)	***
Manufacturer C	0.278 (0.034)	***
Manufacturer D	0.146 (0.039)	***
Manufacturer E	0.121 (0.039)	**
Elapsed Weeks		
2nd week	0.006 (0.014)	
3rd week	0.000 (0.019)	
4th week	-0.032 (0.019)	
5th week	-0.042 (0.020)	*
6th week	-0.059 (0.020)	**
7th week	-0.067 (0.020)	***
8th week	-0.079 (0.020)	***
9th week	-0.100 (0.020)	***
10th week	-0.120 (0.020)	***
11th week	-0.130 (0.020)	***
12th week	-0.137 (0.020)	***
13th week	-0.154 (0.020)	***
Adjusted R-squared		0.870
Standard Error of Regression		0.159
Mean of Dependent Variable		11.836
Standard Deviation of Dependent Variable		0.441
Number of products		536
Size of Panel Data		20,135
Number of Specifications Data		30
Volume of Total Data		664,455

Notes: Values in ( ) indicate standard errors.

***, **, * denote significance at the 0.1%, 1%, 5% level.

(2) Refrigerators and freezers

Dependent Variable: log(average price)		
Intercept	9.992 (0.063)	***
Internal Volume (L)	0.003 (0.000)	***
Switching Chamber (L)	0.003 (0.001)	*
Achievement Ratio of the Energy Saving Target	0.001 (0.000)	***
Dummy Variables		
Deodorizing System	0.136 (0.052)	**
Automatic Icemaker System	0.150 (0.024)	***
Manufacturers		
Manufacturer A	0.231 (0.076)	**
Manufacturer B	0.352 (0.082)	***
Manufacturer C	2.191 (0.120)	***
Manufacturer D	0.288 (0.077)	***
Manufacturer E	0.354 (0.080)	***
Manufacturer F	0.366 (0.085)	***
Manufacturer G	0.431 (0.083)	***
Elapsed Weeks		
2nd week	-0.035 (0.016)	*
3rd week	-0.044 (0.017)	*
4th week	-0.068 (0.018)	***
5th week	-0.055 (0.028)	
6th week	-0.111 (0.019)	***
7th week	-0.143 (0.021)	***
8th week	-0.153 (0.025)	***
9th week	-0.188 (0.020)	***
10th week	-0.199 (0.020)	***
11th week	-0.215 (0.020)	***
12th week	-0.229 (0.020)	***
13th week	-0.239 (0.020)	***
Adjusted R-squared		0.940
Standard Error of Regression		0.163
Mean of Dependent Variable		11.745
Standard Deviation of Dependent Variable		0.662
Number of products		321
Size of Panel Data		10,910
Number of Specifications Data		20
Volume of Total Data		250,930

Notes: Values in ( ) indicate standard errors.

***, **, * denote significance at the 0.1%, 1%, 5% level.

Table 2
Estimation Results of Hedonic Regression: Home Electrical Appliances (2)

(3) Washers and dryers

Dependent Variable: log(average price)		
Intercept	10.304 (0.227)	***
Washing Capacity (kg)	0.123 (0.013)	***
Noise Level (dB)	-0.014 (0.004)	***
Dummy Variables		
Style		
Washer Dryer	0.432 (0.041)	***
Opening and Closing type		
Left-opening	0.368 (0.050)	***
Right-opening	0.503 (0.064)	***
Automatic Cleaning System	0.139 (0.032)	***
Bath Water Drawing Pump System	0.088 (0.043)	*
Manufacturers		
Manufacturer A	0.178 (0.033)	***
Manufacturer B	0.367 (0.058)	***
Manufacturer C	0.239 (0.045)	***
Manufacturer D	0.113 (0.043)	**
Elapsed Weeks		
2nd week	0.009 (0.011)	
3rd week	0.034 (0.016)	*
4th week	0.029 (0.020)	
5th week	0.027 (0.016)	
6th week	0.000 (0.021)	
7th week	0.006 (0.023)	
8th week	0.014 (0.024)	
9th week	0.021 (0.026)	
10th week	0.013 (0.024)	
11th week	0.022 (0.025)	
12th week	0.018 (0.025)	
13th week	0.008 (0.024)	
Adjusted R-squared		0.894
Standard Error of Regression		0.196
Mean of Dependent Variable		11.307
Standard Deviation of Dependent Variable		0.604
Number of products		154
Size of Panel Data		3,880
Number of Specifications Data		21
Volume of Total Data		93,120

Notes: Values in ( ) indicate standard errors.
***, **, * denote significance at the 0.1%, 1%, 5% level.

(4) Rice cookers

Dependent Variable: log(average price)		
Intercept	8.217 (0.083)	***
Power Consumption (Wh)	-0.004 (0.001)	***
Thickness of Inner Pot (mm)	0.127 (0.010)	***
Weight (kg)	0.305 (0.018)	***
Dummy Variables		
Type		
IH Rice Cooker	0.713 (0.058)	***
Pressure IH Rice Cooker	0.711 (0.079)	***
Steam Function	0.362 (0.068)	***
Steam Saving System	0.161 (0.052)	**
Manufacturers		
Manufacturer A	0.298 (0.073)	***
Manufacturer B	0.338 (0.060)	***
Manufacturer C	0.231 (0.089)	**
Manufacturer D	0.406 (0.055)	***
Manufacturer E	0.184 (0.060)	**
Manufacturer F	0.257 (0.057)	***
Elapsed Weeks		
2nd week	-0.044 (0.023)	
3rd week	-0.090 (0.024)	***
4th week	-0.122 (0.026)	***
5th week	-0.145 (0.026)	***
6th week	-0.167 (0.026)	***
7th week	-0.179 (0.027)	***
8th week	-0.201 (0.027)	***
9th week	-0.218 (0.027)	***
10th week	-0.233 (0.027)	***
11th week	-0.243 (0.026)	***
12th week	-0.255 (0.027)	***
13th week	-0.268 (0.026)	***
Adjusted R-squared		0.906
Standard Error of Regression		0.227
Mean of Dependent Variable		10.348
Standard Deviation of Dependent Variable		0.741
Number of products		191
Size of Panel Data		7,349
Number of Specifications Data		19
Volume of Total Data		161,678

Notes: Values in ( ) indicate standard errors.
***, **, * denote significance at the 0.1%, 1%, 5% level.

Table 3

Estimation Results of Hedonic Regression: Home Electrical Appliances (3)

(5) Vacuum cleaners

Dependent Variable: log(average price)		
Intercept	11.684 (0.577)	***
Suction Power (W)	-0.001 (0.000)	***
Noise Level (dB)	-0.042 (0.007)	***
Weight (kg)	0.130 (0.058)	*
Dummy Variables		
Cordless Device	0.663 (0.156)	***
Manufacturers		
Manufacturer A	0.826 (0.249)	***
Manufacturer B	2.212 (0.175)	***
Manufacturer C	1.025 (0.127)	***
Manufacturer D	1.398 (0.168)	***
Manufacturer E	0.570 (0.157)	***
Manufacturer F	1.134 (0.210)	***
Manufacturer G	1.115 (0.207)	***
Manufacturer H	1.334 (0.162)	***
Manufacturer I	1.399 (0.153)	***
Manufacturer J	0.791 (0.127)	***
Manufacturer K	1.417 (0.153)	***
Manufacturer L	1.525 (0.138)	***
Manufacturer M	0.762 (0.159)	***
Elapsed Weeks		
2nd week	-0.112 (0.038)	**
3rd week	-0.137 (0.039)	***
4th week	-0.171 (0.040)	***
5th week	-0.210 (0.041)	***
6th week	-0.233 (0.041)	***
7th week	-0.263 (0.041)	***
8th week	-0.274 (0.041)	***
9th week	-0.287 (0.040)	***
10th week	-0.301 (0.041)	***
11th week	-0.318 (0.041)	***
12th week	-0.324 (0.041)	***
13th week	-0.329 (0.042)	***
Adjusted R-squared		0.741
Standard Error of Regression		0.324
Mean of Dependent Variable		9.989
Standard Deviation of Dependent Variable		0.638
Number of products		150
Size of Panel Data		5,302
Number of Specifications Data		20
Volume of Total Data		121,946

Notes: Values in ( ) indicate standard errors.

***, **, * denote significance at the 0.1%, 1%, 5% level.

(6) Microwaves

Dependent Variable: log(average price)		
Intercept	4.643 (0.260)	***
Maximum Output (W)	0.001 (0.000)	***
Height (mm)	0.013 (0.001)	***
Dummy Variables		
Type		
Microwave Oven	0.246 (0.087)	**
Weight Sensor System	0.306 (0.076)	***
Flat Table	0.170 (0.076)	*
Manufacturers		
Manufacturer A	0.718 (0.100)	***
Manufacturer B	0.330 (0.066)	***
Manufacturer C	0.255 (0.060)	***
Manufacturer D	0.264 (0.063)	***
Manufacturer E	0.341 (0.157)	*
Elapsed Weeks		
2nd week	-0.028 (0.017)	
3rd week	-0.069 (0.018)	***
4th week	-0.118 (0.021)	***
5th week	-0.149 (0.023)	***
6th week	-0.167 (0.021)	***
7th week	-0.195 (0.023)	***
8th week	-0.215 (0.023)	***
9th week	-0.230 (0.023)	***
10th week	-0.203 (0.035)	***
11th week	-0.172 (0.043)	***
12th week	-0.180 (0.041)	***
13th week	-0.187 (0.041)	***
Adjusted R-squared		0.914
Standard Error of Regression		0.259
Mean of Dependent Variable		10.323
Standard Deviation of Dependent Variable		0.886
Number of products		140
Size of Panel Data		4,847
Number of Specifications Data		23
Volume of Total Data		126,022

Notes: Values in ( ) indicate standard errors.

***, **, * denote significance at the 0.1%, 1%, 5% level.

Table 4

Estimation Results of Hedonic Regression: Home Electrical Appliances (4)

(7) Hair dryers and curling irons

Dependent Variable: log(average price)		
Intercept	6.345 (0.227)	***
Hot Air Temperature (degree)	0.005 (0.001)	***
Weight (g)	0.003 (0.000)	***
Dummy Variables		
Manufacturers		
Manufacturer A	0.700 (0.173)	***
Manufacturer B	1.326 (0.151)	***
Manufacturer C	0.990 (0.136)	***
Manufacturer D	1.032 (0.107)	***
Manufacturer E	0.685 (0.099)	***
Manufacturer F	0.530 (0.156)	***
Manufacturer G	0.316 (0.091)	***
Manufacturer H	0.525 (0.103)	***
Manufacturer I	0.277 (0.061)	***
Manufacturer J	0.618 (0.112)	***
Manufacturer K	1.324 (0.135)	***
Manufacturer L	0.168 (0.073)	*
Manufacturer M	0.768 (0.076)	***
Manufacturer N	0.305 (0.085)	***
Manufacturer O	0.594 (0.078)	***
Manufacturer P	1.212 (0.070)	***
Elapsed Weeks		
2nd week	0.056 (0.025)	*
3rd week	0.063 (0.030)	*
4th week	0.031 (0.031)	
5th week	0.006 (0.031)	
6th week	-0.003 (0.032)	
7th week	-0.019 (0.032)	
8th week	-0.047 (0.033)	
9th week	-0.054 (0.034)	
10th week	-0.060 (0.035)	
11th week	-0.061 (0.037)	
12th week	-0.071 (0.038)	
13th week	-0.071 (0.038)	
Adjusted R-squared		0.675
Standard Error of Regression		0.350
Mean of Dependent Variable		8.437
Standard Deviation of Dependent Variable		0.614
Number of products		203
Size of Panel Data		7,314
Number of Specifications Data		8
Volume of Total Data		80,454

Notes: Values in ( ) indicate standard errors.

***, **, * denote significance at the 0.1%, 1%, 5% level.

(8) Air purifiers

Dependent Variable: log(average price)		
Intercept	8.596 (0.249)	***
Effective Floor Area (mat)	0.018 (0.003)	***
Height (mm)	0.001 (0.000)	**
Dummy Variables		
Humidification Function	0.225 (0.042)	***
Dehumidifying Function	0.683 (0.048)	***
Deodorizing Function	0.213 (0.055)	***
Wall Mount Function	0.973 (0.183)	***
Automatic Power Saving System	0.405 (0.053)	***
Concentrated Ion Generating Function	0.346 (0.040)	***
Automatic Cleaning System	0.364 (0.079)	***
Manufacturers		
Manufacturer A	0.389 (0.081)	***
Manufacturer B	1.262 (0.064)	***
Manufacturer C	0.964 (0.202)	***
Manufacturer D	0.473 (0.059)	***
Manufacturer E	0.300 (0.073)	***
Manufacturer F	0.586 (0.075)	***
Manufacturer G	0.695 (0.129)	***
Manufacturer H	0.208 (0.053)	***
Manufacturer I	0.393 (0.063)	***
Manufacturer J	0.631 (0.067)	***
Elapsed Weeks		
2nd week	0.012 (0.019)	
3rd week	0.002 (0.022)	
4th week	-0.015 (0.023)	
5th week	-0.030 (0.026)	
6th week	-0.038 (0.032)	
7th week	-0.051 (0.033)	
8th week	-0.060 (0.033)	
9th week	-0.080 (0.042)	
10th week	-0.088 (0.042)	*
11th week	-0.085 (0.045)	
12th week	-0.091 (0.046)	*
13th week	-0.110 (0.045)	*
Adjusted R-squared		0.914
Standard Error of Regression		0.149
Mean of Dependent Variable		10.573
Standard Deviation of Dependent Variable		0.507
Number of products		103
Size of Panel Data		3,291
Number of Specifications Data		32
Volume of Total Data		115,185

Notes: Values in ( ) indicate standard errors.

***, **, * denote significance at the 0.1%, 1%, 5% level.

Table 5

Estimation Results of Hedonic Regression: Digital Consumer Electronics (1)

(1) GPS navigations

Dependent Variable: log(average price)		
Intercept	8.058 (0.174)	***
Screen Size (inch)	0.331 (0.019)	***
Dummy Variables		
Recording Medium Type		
HDD	0.413 (0.080)	***
SSD	0.181 (0.063)	**
Rear Monitor Device	0.405 (0.028)	***
Terrestrial Digital Tuner	0.624 (0.084)	***
Vehicle Information and Communication System	0.232 (0.045)	***
Blu-ray Disk Device	0.491 (0.073)	***
Voice Recognition System	0.160 (0.036)	***
High-resolution Audio Device	0.428 (0.051)	***
Manufacturers		
Manufacturer A	0.589 (0.059)	***
Manufacturer B	0.344 (0.122)	**
Manufacturer C	0.202 (0.071)	**
Manufacturer D	0.797 (0.123)	***
Manufacturer E	0.585 (0.127)	***
Manufacturer F	0.825 (0.123)	***
Manufacturer G	0.730 (0.139)	***
Manufacturer H	0.273 (0.067)	***
Manufacturer I	0.384 (0.073)	***
Manufacturer J	0.744 (0.120)	***
Elapsed Weeks		
2nd week	-0.045 (0.011)	***
3rd week	-0.074 (0.015)	***
4th week	-0.096 (0.016)	***
5th week	-0.112 (0.016)	***
6th week	-0.128 (0.016)	***
7th week	-0.147 (0.016)	***
8th week	-0.160 (0.017)	***
9th week	-0.162 (0.017)	***
10th week	-0.171 (0.017)	***
11th week	-0.174 (0.017)	***
12th week	-0.181 (0.017)	***
13th week	-0.176 (0.017)	***
Adjusted R-squared		0.896
Standard Error of Regression		0.184
Mean of Dependent Variable		11.418
Standard Deviation of Dependent Variable		0.571
Number of products		152
Size of Panel Data		4,891
Number of Specifications Data		30
Volume of Total Data		161,403

Notes: Values in ( ) indicate standard errors.

***, **, * denote significance at the 0.1%, 1%, 5% level.

(2) External hard drives

Dependent Variable: log(average price)		
Intercept	8.961 (0.078)	***
Memory Capacity (TB)	0.174 (0.000)	***
Dummy Variables		
Cooling Fan Device	0.263 (0.056)	***
IEEE1394b	0.674 (0.069)	***
Lan	0.553 (0.155)	***
Thunderbolt	0.821 (0.123)	***
Manufacturers		
Manufacturer A	0.187 (0.045)	***
Manufacturer B	0.164 (0.041)	***
Manufacturer C	0.252 (0.102)	*
Manufacturer D	0.135 (0.061)	*
Manufacturer E	0.191 (0.070)	**
Elapsed Weeks		
2nd week	-0.006 (0.014)	
3rd week	-0.004 (0.015)	
4th week	-0.010 (0.015)	
5th week	-0.009 (0.015)	
6th week	-0.013 (0.015)	
7th week	-0.018 (0.016)	
8th week	-0.019 (0.017)	
9th week	-0.022 (0.017)	
10th week	-0.029 (0.017)	
11th week	-0.039 (0.018)	*
12th week	-0.047 (0.018)	**
13th week	-0.054 (0.018)	**
Adjusted R-squared		0.850
Standard Error of Regression		0.260
Mean of Dependent Variable		9.727
Standard Deviation of Dependent Variable		0.671
Number of products		303
Size of Panel Data		10,908
Number of Specifications Data		13
Volume of Total Data		174,528

Notes: Values in ( ) indicate standard errors.

***, **, * denote significance at the 0.1%, 1%, 5% level.

Table 6

Estimation Results of Hedonic Regression: Digital Consumer Electronics (2)

(3) LCD TVs

Dependent Variable: log(average price)		
Intercept	9.327 (0.048)	***
Screen Size (inch)	0.034 (0.001)	***
Pixel Number (million pixels)	0.059 (0.000)	***
Dummy Variables		
IPS system	0.123 (0.035)	***
3D Television	0.124 (0.028)	***
Screen Split Display System	0.105 (0.035)	**
Speed Converting Circuit		
4 times	0.141 (0.033)	***
16 times	0.271 (0.079)	***
20 times	0.562 (0.068)	***
Digital Tuner 9 Channels	0.195 (0.041)	***
Internal Blu-ray Function	0.550 (0.054)	***
HDMI 4 terminals	0.148 (0.031)	***
ARC Function	0.084 (0.032)	**
Manufacturers		
Manufacturer A	0.268 (0.030)	***
Manufacturer B	0.155 (0.023)	***
Manufacturer C	0.181 (0.045)	***
Manufacturer D	0.161 (0.035)	***
Manufacturer E	0.688 (0.068)	***
Manufacturer F	0.217 (0.055)	***
Manufacturer G	0.486 (0.065)	***
Manufacturer H	0.297 (0.056)	***
Manufacturer I	0.406 (0.047)	***
Manufacturer J	0.300 (0.042)	***
Manufacturer K	0.282 (0.055)	***
Manufacturer L	0.323 (0.041)	***
Elapsed Weeks		
2nd week	-0.049 (0.009)	***
3rd week	-0.080 (0.010)	***
4th week	-0.109 (0.011)	***
5th week	-0.135 (0.011)	***
6th week	-0.162 (0.011)	***
7th week	-0.178 (0.011)	***
8th week	-0.199 (0.012)	***
9th week	-0.216 (0.012)	***
10th week	-0.231 (0.012)	***
11th week	-0.242 (0.012)	***
12th week	-0.249 (0.013)	***
13th week	-0.259 (0.013)	***
Adjusted R-squared		0.981
Standard Error of Regression		0.120
Mean of Dependent Variable		11.605
Standard Deviation of Dependent Variable		0.872
Number of products		188
Size of Panel Data		6,666
Number of Specifications Data		39
Volume of Total Data		279,972

Notes: Values in ( ) indicate standard errors.
***, **, * denote significance at the 0.1%, 1%, 5% level.

(4) LCD monitors

Dependent Variable: log(average price)		
Intercept	6.690 (0.209)	***
Screen Size (inch)	0.061 (0.007)	***
Resolution (dpi)	0.000 (0.000)	***
Response Speed (ms)	0.038 (0.007)	***
Luminance (cd/m2)	0.004 (0.001)	***
Dummy Variables		
Monitor Type		
Square	0.379 (0.098)	***
3D Function	0.433 (0.111)	***
Micro USB	0.196 (0.072)	**
Panel Type		
AH-IPS	0.415 (0.065)	***
IPS	0.287 (0.073)	***
TN	0.188 (0.079)	*
Touch Panel Function	0.805 (0.095)	***
USB Hub	0.260 (0.040)	***
Manufacturers		
Manufacturer A	0.233 (0.041)	***
Manufacturer B	0.234 (0.055)	***
Manufacturer C	0.245 (0.079)	**
Manufacturer D	0.576 (0.072)	***
Manufacturer E	0.182 (0.054)	***
Manufacturer F	0.444 (0.078)	***
Elapsed Weeks		
2nd week	-0.009 (0.010)	
3rd week	-0.015 (0.011)	
4th week	-0.023 (0.011)	*
5th week	-0.029 (0.015)	
6th week	-0.035 (0.015)	*
7th week	-0.039 (0.015)	**
8th week	-0.043 (0.015)	**
9th week	-0.042 (0.015)	**
10th week	-0.044 (0.016)	**
11th week	-0.049 (0.016)	**
12th week	-0.056 (0.017)	***
13th week	-0.053 (0.017)	**
Adjusted R-squared		0.907
Standard Error of Regression		0.234
Mean of Dependent Variable		10.604
Standard Deviation of Dependent Variable		0.769
Number of products		193
Size of Panel Data		6,566
Number of Specifications Data		46
Volume of Total Data		321,734

Notes: Values in ( ) indicate standard errors.
***, **, * denote significance at the 0.1%, 1%, 5% level.

Table 7

Estimation Results of Hedonic Regression: Digital Consumer Electronics (3)

(5) Printers

Dependent Variable: log(average price)		
Intercept	6.794 (0.204)	***
Maximum Number of Layered Sheets (sheet)	0.001 (0.000)	***
Width (mm)	0.004 (0.001)	***
Depth (mm)	0.002 (0.000)	***
Dummy Variables		
Printer Type		
Color Laser	0.835 (0.105)	***
Monochrome Laser	0.862 (0.107)	***
Mobile Function	1.376 (0.086)	***
FAX Function	0.283 (0.054)	***
Direct Printing System	0.307 (0.075)	***
Label Printing System	0.257 (0.082)	**
Manufacturers		
Manufacturer A	0.626 (0.184)	***
Manufacturer B	0.386 (0.072)	***
Manufacturer C	0.745 (0.088)	***
Manufacturer D	0.545 (0.131)	***
Manufacturer E	0.572 (0.134)	***
Manufacturer F	0.428 (0.131)	***
Manufacturer G	0.571 (0.178)	**
Elapsed Weeks		
2nd week	-0.001 (0.013)	
3rd week	-0.010 (0.014)	
4th week	-0.008 (0.016)	
5th week	-0.012 (0.018)	
6th week	-0.017 (0.021)	
7th week	-0.023 (0.021)	
8th week	-0.037 (0.022)	
9th week	-0.047 (0.026)	
10th week	-0.044 (0.028)	
11th week	-0.048 (0.028)	
12th week	-0.050 (0.028)	
13th week	-0.060 (0.030)	*
Adjusted R-squared		0.826
Standard Error of Regression		0.403
Mean of Dependent Variable		10.605
Standard Deviation of Dependent Variable		0.965
Number of products		264
Size of Panel Data		9,983
Number of Specifications Data		32
Volume of Total Data		349,405

Notes: Values in ( ) indicate standard errors.

***, **, * denote significance at the 0.1%, 1%, 5% level.

(6) Blu-ray and DVD recorders

Dependent Variable: log(average price)		
Intercept	10.662 (0.047)	***
HDD Capacity (TB)	0.000 (0.000)	***
Simultaneously Recordable Number of Programs	0.117 (0.014)	***
Recording Capacity for a long time (times)	0.007 (0.002)	**
Dummy Variables		
Coaxial Digital Audio Output Terminal	1.127 (0.028)	***
Ultra HD Blu-ray Function	0.194 (0.036)	***
Manufacturers		
Manufacturer A	0.088 (0.032)	**
Manufacturer B	0.086 (0.033)	**
Elapsed Weeks		
2nd week	-0.013 (0.014)	
3rd week	-0.086 (0.015)	***
4th week	-0.118 (0.016)	***
5th week	-0.148 (0.017)	***
6th week	-0.185 (0.016)	***
7th week	-0.219 (0.016)	***
8th week	-0.235 (0.021)	***
9th week	-0.243 (0.021)	***
10th week	-0.248 (0.021)	***
11th week	-0.252 (0.021)	***
12th week	-0.262 (0.020)	***
13th week	-0.262 (0.019)	***
Adjusted R-squared		0.874
Standard Error of Regression		0.153
Mean of Dependent Variable		10.999
Standard Deviation of Dependent Variable		0.430
Number of products		90
Size of Panel Data		3,143
Number of Specifications Data		47
Volume of Total Data		157,150

Notes: Values in ( ) indicate standard errors.

***, **, * denote significance at the 0.1%, 1%, 5% level.

Table 8

Estimation Results of Hedonic Regression: Digital Consumer Electronics (4)

(7) Headphones

Dependent Variable: log(average price)		
Intercept	5.150 (0.962)	***
Minimum Reproduction Frequency (Hz)	-0.040 (0.007)	***
Impedance (ohm)	0.002 (0.000)	***
Sound Pressure Sensitivity (dB)	0.026 (0.009)	**
Weight (g)	0.004 (0.001)	***
Dummy Variables		
Type		
Canal-type	0.504 (0.123)	***
Ear-hooking	0.832 (0.263)	**
Standard Plug Device	0.320 (0.117)	**
Noise Cancel System	0.497 (0.192)	**
High Resolution Function	1.121 (0.100)	***
Remote Control Cable Device	0.645 (0.097)	***
Wireless System	0.736 (0.125)	***
Manufacturers		
Manufacturer A	1.302 (0.308)	***
Manufacturer B	0.921 (0.149)	***
Manufacturer C	0.399 (0.108)	***
Manufacturer D	2.648 (0.110)	***
Manufacturer E	0.624 (0.152)	***
Manufacturer F	2.535 (0.153)	***
Manufacturer G	0.943 (0.127)	***
Manufacturer H	2.073 (0.150)	***
Manufacturer I	1.384 (0.156)	***
Manufacturer J	3.723 (0.236)	***
Elapsed Weeks		
2nd week	-0.015 (0.013)	
3rd week	-0.023 (0.014)	
4th week	-0.026 (0.015)	
5th week	-0.045 (0.017)	**
6th week	-0.054 (0.018)	**
7th week	-0.052 (0.019)	**
8th week	-0.044 (0.020)	*
9th week	-0.038 (0.023)	
10th week	-0.046 (0.023)	*
11th week	-0.061 (0.024)	**
12th week	-0.072 (0.025)	**
13th week	-0.073 (0.025)	**
Adjusted R-squared		0.818
Standard Error of Regression		0.516
Mean of Dependent Variable		8.880
Standard Deviation of Dependent Variable		1.210
Number of products		429
Size of Panel Data		15,186
Number of Specifications Data		23
Volume of Total Data		394,836

Notes: Values in ( ) indicate standard errors.

***, **, * denote significance at the 0.1%, 1%, 5% level.

Other 16 manufacturers are significance at the 0.1% level.

(8) Camcorders

Dependent Variable: log(average price)		
Intercept	8.801 (0.211)	***
Pixel Number (million pixels)	0.034 (0.000)	***
Photographable Time (minute)	0.004 (0.001)	***
Weight (g)	0.000 (0.000)	**
Dummy Variables		
Finder Device	0.507 (0.199)	*
AV Output Function	0.860 (0.098)	***
DC Input Funtion	0.781 (0.131)	***
Micro USB 2.0	0.198 (0.082)	*
Manufacturers		
Manufacturer A	0.268 (0.030)	***
Manufacturer B	0.155 (0.023)	***
Manufacturer C	0.323 (0.041)	***
Elapsed Weeks		
2nd week	-0.049 (0.009)	***
3rd week	-0.080 (0.010)	***
4th week	-0.109 (0.011)	***
5th week	-0.135 (0.011)	***
6th week	-0.162 (0.011)	***
7th week	-0.178 (0.011)	***
8th week	-0.199 (0.012)	***
9th week	-0.216 (0.012)	***
10th week	-0.231 (0.012)	***
11th week	-0.242 (0.012)	***
12th week	-0.249 (0.013)	***
13th week	-0.259 (0.013)	***
Adjusted R-squared		0.981
Standard Error of Regression		0.120
Mean of Dependent Variable		11.605
Standard Deviation of Dependent Variable		0.872
Number of products		188
Size of Panel Data		6,666
Number of Specifications Data		39
Volume of Total Data		279,972

Notes: Values in ( ) indicate standard errors.

***, **, * denote significance at the 0.1%, 1%, 5% level.

Table 9

Estimation Results of Hedonic Regression: Digital Consumer Electronics (5)

(9) Laptops

Dependent Variable: log(average price)		
Intercept	9.215 (0.358)	***
Display Size (inch)	0.052 (0.021)	*
Resolution (dpi)	0.000 (0.000)	***
SSD Capacity (TB)	0.001 (0.000)	*
HDD Capacity (TB)	0.000 (0.000)	***
Revolution Speed (rpm)	0.000 (0.000)	***
Memory Capacity (GB)	0.014 (0.005)	**
Number of Memory Slot	0.150 (0.028)	***
Video Memory (MB)	0.000 (0.000)	***
Battery Drive Time (h)	0.018 (0.003)	***
Depth (mm)	-0.004 (0.001)	**
Dummy Variables		
Touch Panel Corresponding to Windows 8	0.088 (0.018)	***
CPU		
Core i3/2 Cores	0.177 (0.018)	***
Core i5/2 Cores	0.268 (0.024)	***
Core i7/2 Cores	0.413 (0.038)	***
Core i3/4 Cores	0.343 (0.028)	***
CD Drive	0.366 (0.054)	***
LAN System	0.191 (0.089)	*
Wi-Fi Direct System	0.212 (0.023)	***
WiDi System	0.064 (0.031)	*
Bluetooth System	0.071 (0.025)	**
3D Acceleration Sensor Device	0.138 (0.057)	*
Acceleration Sensor Device	0.194 (0.029)	***
OS		
Windows 10	0.312 (0.032)	***
Windows 7	0.085 (0.026)	**
Microsoft Office Integrated Software System	0.259 (0.018)	***
Manufacturers		
Manufacturer A	0.180 (0.026)	***
Manufacturer B	0.082 (0.036)	*
Manufacturer C	0.716 (0.062)	***
Manufacturer D	0.161 (0.031)	***
Elapsed Weeks		
2nd week	-0.021 (0.004)	***
3rd week	-0.031 (0.004)	***
4th week	-0.040 (0.005)	***
5th week	-0.036 (0.005)	***
6th week	-0.035 (0.006)	***
7th week	-0.033 (0.007)	***
8th week	-0.036 (0.007)	***
9th week	-0.045 (0.008)	***
10th week	-0.052 (0.008)	***
11th week	-0.053 (0.008)	***
12th week	-0.065 (0.008)	***
13th week	-0.071 (0.008)	***
Adjusted R-squared		0.882
Standard Error of Regression		0.152
Mean of Dependent Variable		11.422
Standard Deviation of Dependent Variable		0.443
Number of products		527
Size of Panel Data		14,716
Number of Specifications Data		66
Volume of Total Data		1,015,404

Notes: Values in ( ) indicate standard errors.

***, **, * denote significance at the 0.1%, 1%, 5% level.

(10) Desktops

Dependent Variable: log(average price)		
Intercept	9.694 (0.210)	***
CPU Frequency (GHz)	0.144 (0.032)	***
Memory Capacity (GB)	0.018 (0.006)	**
HDD Capacity (TB)	0.045 (0.000)	**
Display Size (inch)	0.021 (0.008)	**
Resolution (dpi)	0.000 (0.000)	***
Dummy Variables		
Case Structure		
Integrated Liquid Crystal Display	0.149 (0.050)	**
Tower Type	0.102 (0.038)	**
CPU		
Core i3	0.121 (0.044)	**
Core i5	0.175 (0.030)	***
Core i7	0.182 (0.035)	***
DDR4 Memory System	0.160 (0.073)	*
Hybrid HDD System	0.466 (0.068)	***
Integrated Software System		
Office Home and Business 2013	0.232 (0.039)	***
Office Home and Business Premium	0.312 (0.043)	***
Office Personal 2013	0.248 (0.043)	***
Office Personal Premium	0.304 (0.053)	***
Touch Panel Corresponding to Windows 8	0.130 (0.024)	***
3D Function	0.184 (0.026)	***
4K Output Function	0.070 (0.027)	*
Manufacturers		
Manufacturer A	0.169 (0.046)	***
Manufacturer B	0.334 (0.035)	***
Manufacturer C	0.177 (0.055)	**
Manufacturer D	0.346 (0.031)	***
Manufacturer E	0.440 (0.042)	***
Manufacturer F	0.324 (0.030)	***
Elapsed Weeks		
2nd week	-0.008 (0.006)	
3rd week	-0.027 (0.007)	***
4th week	-0.028 (0.008)	***
5th week	-0.033 (0.009)	***
6th week	-0.043 (0.009)	***
7th week	-0.054 (0.009)	***
8th week	-0.064 (0.010)	***
9th week	-0.070 (0.011)	***
10th week	-0.083 (0.011)	***
11th week	-0.083 (0.012)	***
12th week	-0.103 (0.012)	***
13th week	-0.112 (0.013)	***
Adjusted R-squared		0.892
Standard Error of Regression		0.125
Mean of Dependent Variable		11.778
Standard Deviation of Dependent Variable		0.381
Number of products		213
Size of Panel Data		6,323
Number of Specifications Data		45
Volume of Total Data		303,504

Notes: Values in ( ) indicate standard errors.

***, **, * denote significance at the 0.1%, 1%, 5% level.

Table 10

Estimation Results of Hedonic Regression: Digital Consumer Electronics (6)

(11) Point-and-shoot cameras

Dependent Variable: log(average price)		
Intercept	4.958 (0.303)	***
Waterproof Performance (m)	0.011 (0.002)	***
Internal Memory Capacity (MB)	0.000 (0.000)	***
Liquid Crystal Monitor Size (inch)	0.912 (0.116)	***
Finder (million pixels)	0.185 (0.000)	***
Weight (g)	0.001 (0.000)	***
Dummy Variables		
Mannual Focus Function	0.110 (0.042)	**
Consecutive Imaging Function	1.415 (0.092)	***
AF Automatic Tracking Function	0.340 (0.046)	***
Liquid Crystal Tilt Monitor	0.223 (0.035)	***
Touch Panel Function	0.106 (0.045)	*
Image Element CMOS Device	0.344 (0.052)	***
RAW Function	0.289 (0.044)	***
RAW(DNG) Function	1.106 (0.154)	***
Optical Media Device	0.590 (0.074)	***
Micro SDHC System	0.182 (0.082)	*
Memory Stick Duo Function	0.413 (0.047)	***
Manufacturers		
Manufacturer A	0.167 (0.048)	***
Manufacturer B	0.217 (0.063)	***
Manufacturer C	1.386 (0.119)	***
Manufacturer D	0.195 (0.047)	***
Manufacturer E	0.524 (0.069)	***
Elapsed Weeks		
2nd week	-0.015 (0.003)	***
3rd week	-0.028 (0.004)	***
4th week	-0.044 (0.004)	***
5th week	-0.055 (0.005)	***
6th week	-0.067 (0.005)	***
7th week	-0.076 (0.005)	***
8th week	-0.092 (0.007)	***
9th week	-0.104 (0.008)	***
10th week	-0.110 (0.009)	***
11th week	-0.120 (0.009)	***
12th week	-0.130 (0.010)	***
13th week	-0.135 (0.010)	***
Adjusted R-squared		0.952
Standard Error of Regression		0.156
Mean of Dependent Variable		10.193
Standard Deviation of Dependent Variable		0.715
Number of products		149
Size of Panel Data		5,206
Number of Specifications Data		80
Volume of Total Data		432,098

Notes: Values in ( ) indicate standard errors.

***, **, * denote significance at the 0.1%, 1%, 5% level.

(12) DSLR and mirrorless cameras

Dependent Variable: log(average price)		
Intercept	4.551 (0.997)	***
Pixel Number (million pixels)	0.019 (0.000)	***
Image Element (mm2)	0.001 (0.000)	***
Photographic Sensitivity (ISO)	0.000 (0.000)	***
Liquid Crystal Monitor Size (inch)	1.401 (0.316)	***
Finder Visual Field Ratio	0.002 (0.001)	***
Height (mm)	0.013 (0.002)	***
Movie Recording Pixel Number (million pixels)	0.054 (0.000)	**
Dummy Variables		
Micro SDHC System	0.290 (0.141)	*
Lap Time Measuring System	0.343 (0.068)	***
Lens Attachment Structure	0.224 (0.038)	***
Manufacturers		
Manufacturer A	0.387 (0.069)	***
Manufacturer B	0.827 (0.092)	***
Manufacturer C	0.458 (0.110)	***
Manufacturer D	0.408 (0.123)	***
Manufacturer E	0.141 (0.066)	*
Manufacturer F	0.487 (0.093)	***
Elapsed Weeks		
2nd week	-0.004 (0.005)	
3rd week	-0.008 (0.006)	
4th week	-0.019 (0.006)	**
5th week	-0.025 (0.007)	***
6th week	-0.031 (0.007)	***
7th week	-0.034 (0.008)	***
8th week	-0.040 (0.009)	***
9th week	-0.046 (0.011)	***
10th week	-0.052 (0.011)	***
11th week	-0.057 (0.011)	***
12th week	-0.057 (0.010)	***
13th week	-0.053 (0.012)	***
Adjusted R-squared		0.874
Standard Error of Regression		0.224
Mean of Dependent Variable		11.494
Standard Deviation of Dependent Variable		0.630
Number of products		138
Size of Panel Data		5,489
Number of Specifications Data		52
Volume of Total Data		301,895

Notes: Values in ( ) indicate standard errors.

***, **, * denote significance at the 0.1%, 1%, 5% level.

Appendix 1
Additional Selection Criterion of Matched Pairs (1): *Relative Difference in Quality*

In order to ensure robustness of the key findings against a lurking error caused by the insufficient criteria of selecting matched pairs, we conduct a supplementary analysis which excludes the possible combinations of a new product and an old one that are likely to belong to different line-ups (e.g. a pair of "low-end old model" and "high-end new model"). In this Appendix, we introduce an additional selection criterion which relies on the idea of the *relative difference in quality* between a new product and an old one to eliminate those combinations as much as possible and then we calculate the QIR of matched pairs of products based on the new criteria.

According to the data sets, there is a tendency that the quality difference between a new product and an old one is relatively large if those products belong to different line-ups, while the difference is relatively small if those products belong to the same line-up. This observation suggests that, if we measure the quality differences for all the matched pairs selected according to the four criteria in the main text and observe their distribution, then the quality differences for the true matched pairs, belonging to the same line-up, are very likely to be on the smaller end. Our additional criterion for the true matched pairs thus leads that the quality difference has to be smaller than the average over all the possible matched pairs selected based on the criteria 1 to 4.

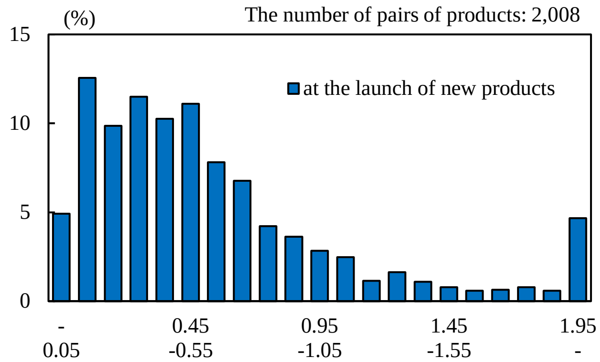
The results of this supplementary analysis using the relative difference in quality as an additional selection criterion, however, does not qualitatively differ from the results in the benchmark analysis mentioned in the main text. In other words, even though the mode value of the distribution measured immediately after the launch of a new product slightly decreases to about 0.3-0.5 for home electrical appliances and about 0.4-0.6 for digital consumer electronics, the conclusion of the benchmark analysis, which supports the appropriateness of the 50% rule, is still qualitatively valid. Therefore, the robustness of the key findings in the benchmark analysis has been confirmed.

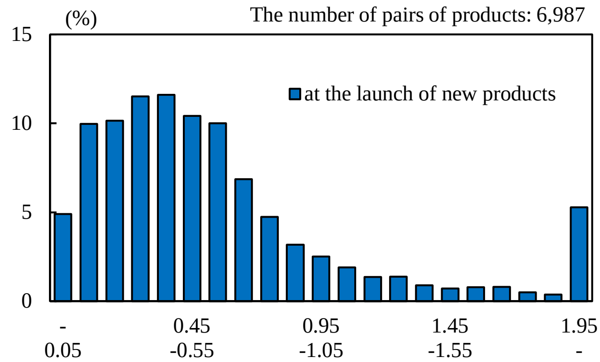
Appendix Figure A1 (*Relative Difference in Quality*)
Distribution of Quality Improvement Ratios: Overview

(1) Home electrical appliances

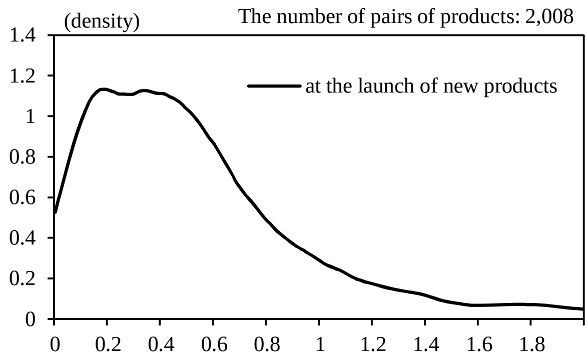
(2) Digital consumer electronics

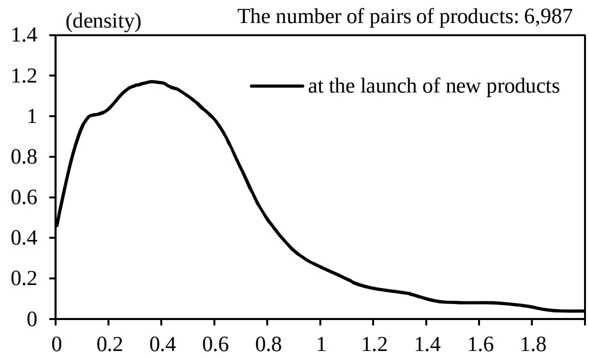
(Description using histogram)



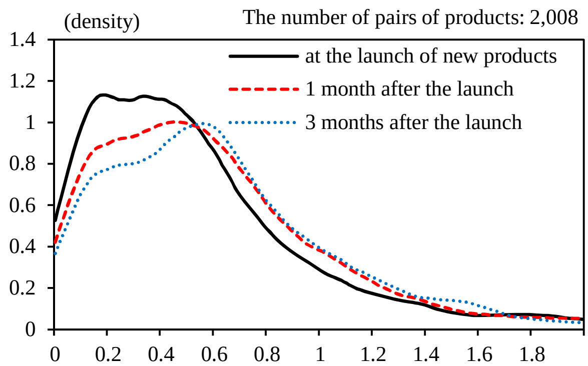


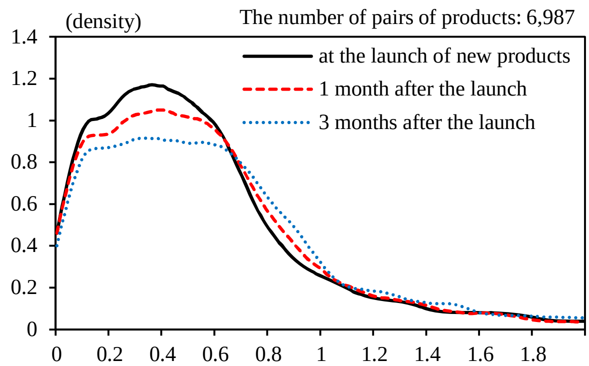
(Approximation using Kernel density graph)





(Shift in distribution of quality improvement ratio)



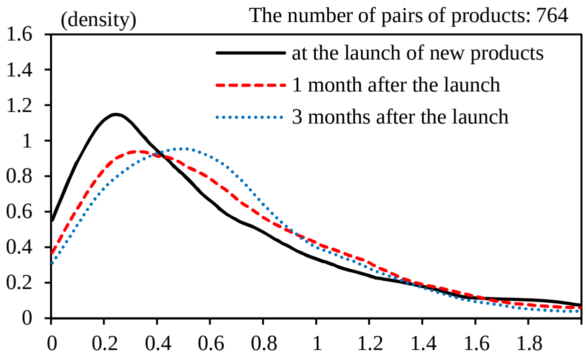


Note: A kernel density estimation enables to approximate a discrete probability distribution by tracing a smooth curve. In these figures, band width is decided by the *Silverman rule* and a kernel function is assumed to be the quadratic *Epanechnikov kernel*. Also, we conduct outlier processing by trimming the upper and lower 1 percent tails of matched pairs of new products and old products.

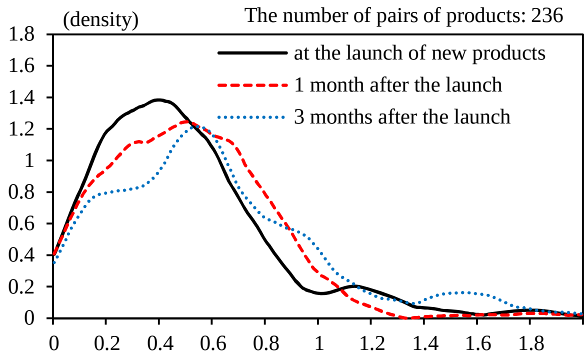
Appendix Figure A2 (*Relative Difference in Quality*)

Distribution of Quality Improvement Ratios: Home Electrical Appliances

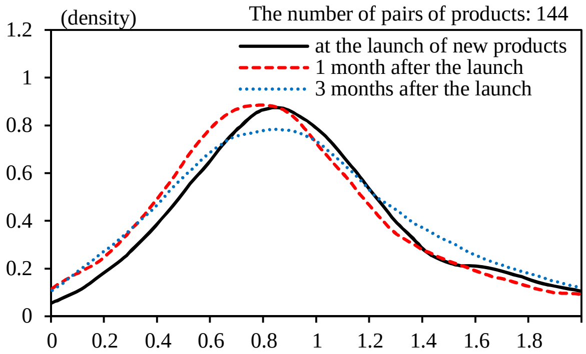
(1) Air conditioners



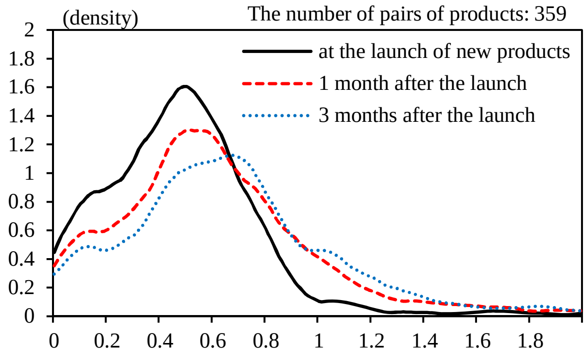
(2) Refrigerators and freezers



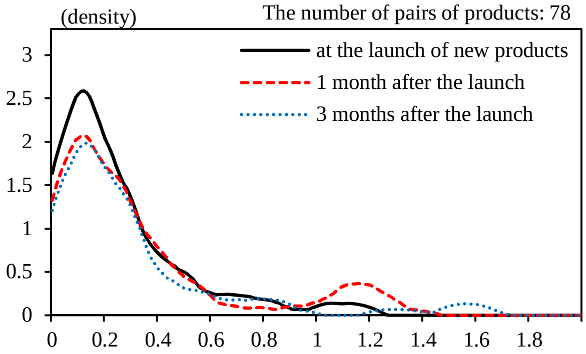
(3) Washers and dryers



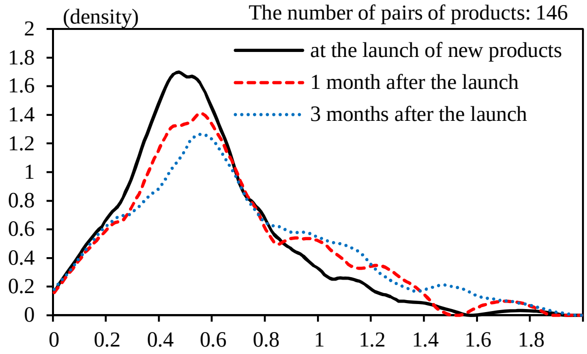
(4) Rice cookers



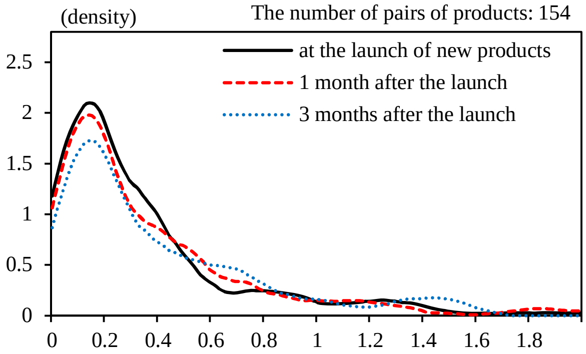
(5) Vacuum cleaners



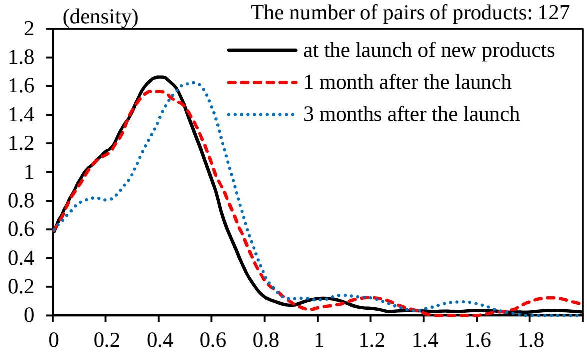
(6) Microwaves



(7) Hair dryers and curling irons



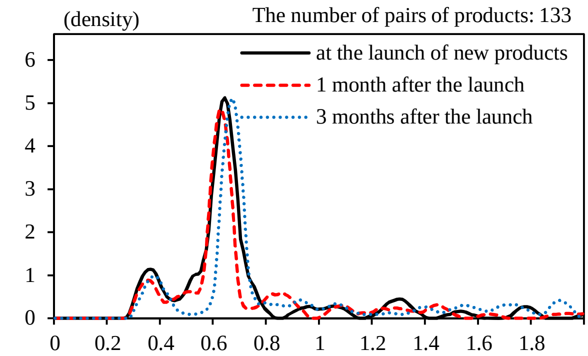
(8) Air purifiers



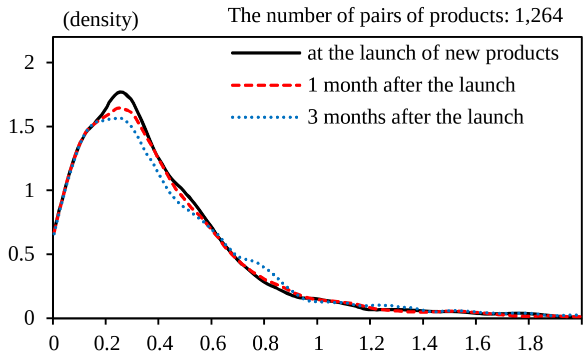
Appendix Figure A3 (*Relative Difference in Quality*)

Distribution of Quality Improvement Ratios: Digital Consumer Electronics (1)

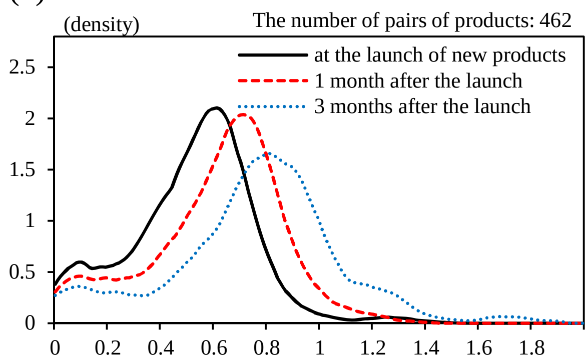
(1) GPS navigations



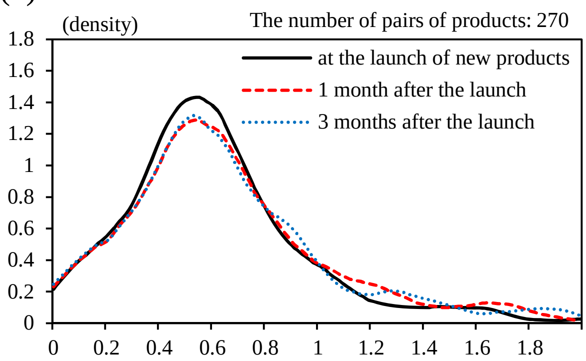
(2) External hard drives



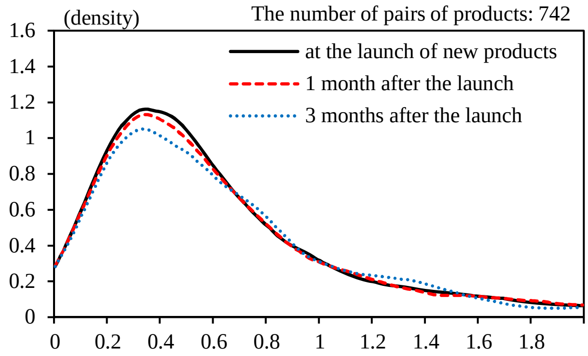
(3) LCD TVs



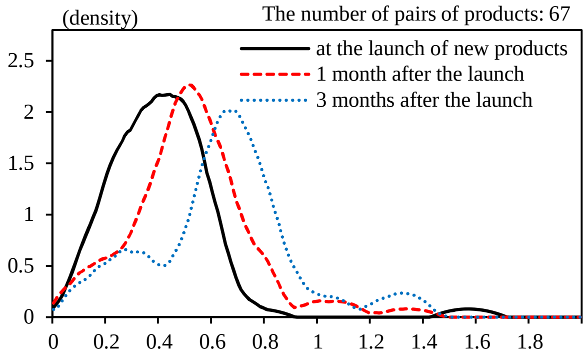
(4) LCD monitors



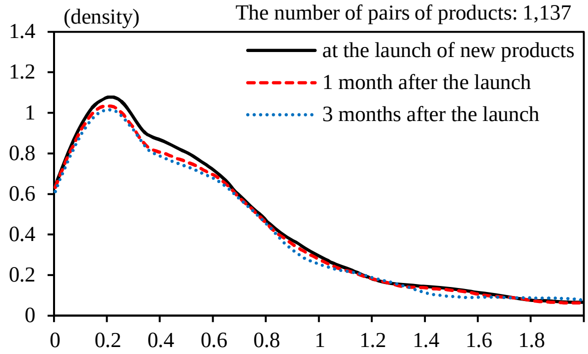
(5) Printers



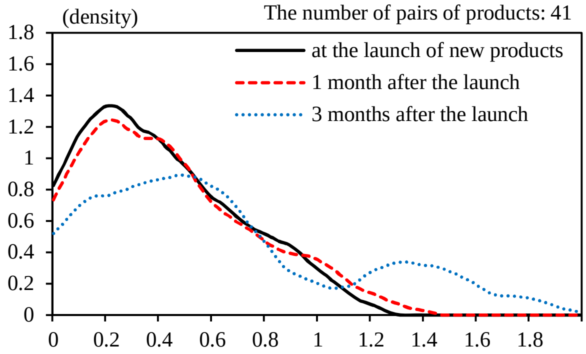
(6) Blu-ray and DVD recorders



(7) Headphones



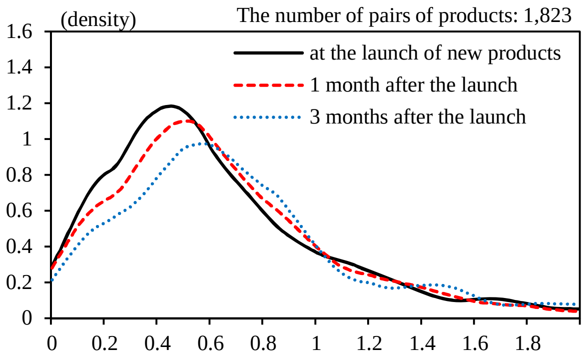
(8) Camcorders



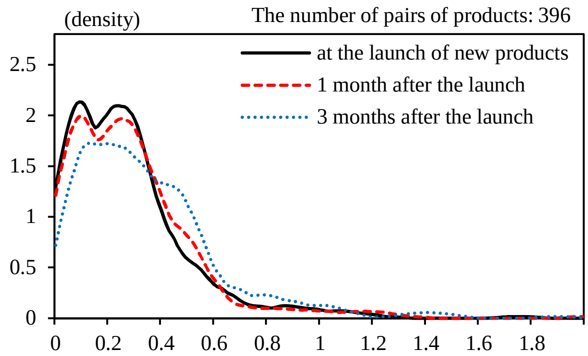
Appendix Figure A4 (*Relative Difference in Quality*)

Distribution of Quality Improvement Ratios: Digital Consumer Electronics (2)

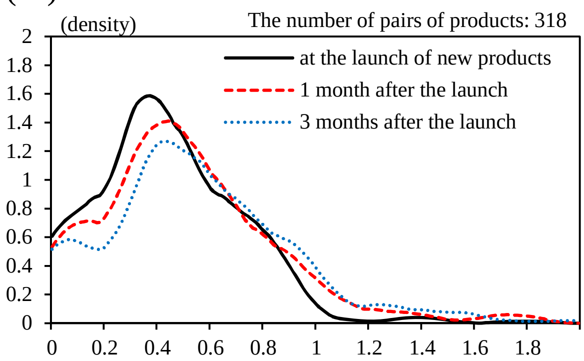
(9) Laptops



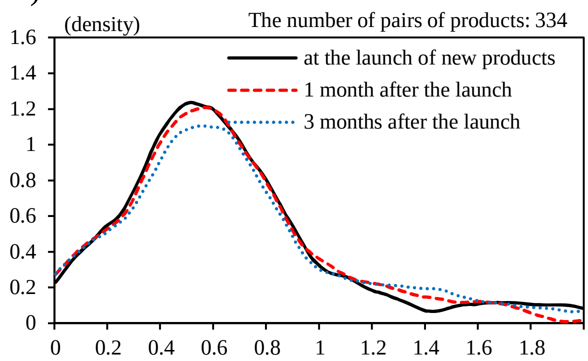
(10) Desktops



(11) Point-and-shoot cameras



(12) DSLR and mirrorless cameras



Appendix 2
Additional Selection Criterion of Matched Pairs (2): *Levenshtein Distance*

As with the awareness of ensuring robustness raised in the previous Appendix, in this Appendix, we take in another additional selection criterion of matched pairs of products which relies on the *Levenshtein distance* so as to exclude the possible combinations of a new product and an old one that are likely to belong to different line-ups. And then we calculate the QIR of matched pairs of products selected under the new criteria.

Before showing the results of the analysis, we would like to briefly introduce the concept of the Levenshtein distance. The distance is a kind of the *minimum edit distance* which quantifies the extent of variation between two strings by measuring the minimum number of editing operations (insertion, deletion, substitution) needed to transform one string into the other.[a] For example, the Levenshtein distance between *intention* and *execution* is calculated as 5 because the transformation needs the following operations:

intention	
↓	1. delete the 1st letter "i"
ntention	
↓	2. substitute 1st letter "n" by "e"
etention	
↓	3. substitute 2nd letter "t" by "x"
exention	
↓	4. insert "u" between 4th letter and 5th letter
exenution	
↓	5. substitute 4th letter "n" by "c"
execution	

In light of a model name of each product, the Levenshtein distance between a pair of a new product and an old one has a propensity to be large if those products belong to different line-ups, and *vice versa*. Therefore, by eliminating the matched pairs of products at a further distance compared to the average over all the possible matched pairs selected, we could mitigate the possible bias caused by faultiness of selection criteria of matched pairs.

The results of the analysis by using the Levenshtein distance as another additional selection criterion, however, are almost the same as the results in the benchmark analysis. Therefore, the robustness of the benchmark analysis has been confirmed again.

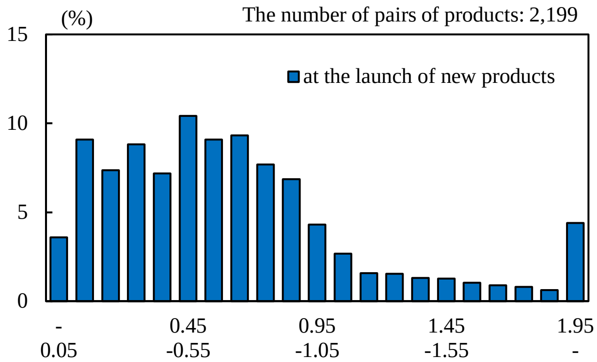
[a] For details, see Jurafsky and Martin (2008), "Speech and Language Processing: An Introduction to Natural Language Processing, Computational Linguistics, and Speech Recognition," Prentice Hall.

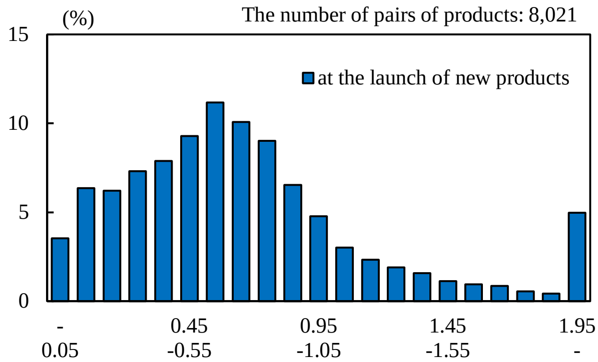
Appendix Figure B1 (*Levenshtein Distance*)
Distribution of Quality Improvement Ratios: Overview

(1) Home electrical appliances

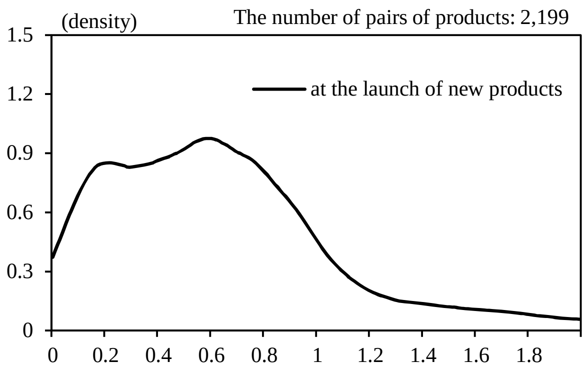
(2) Digital consumer electronics

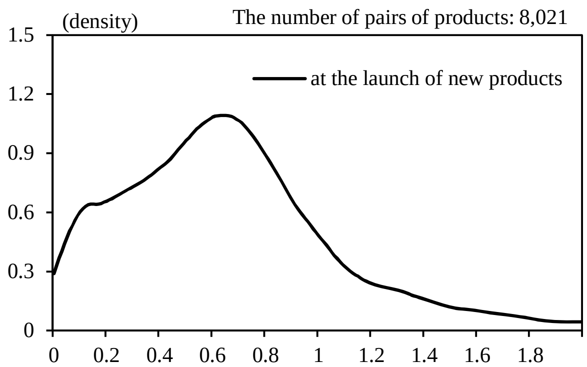
(Description using histogram)



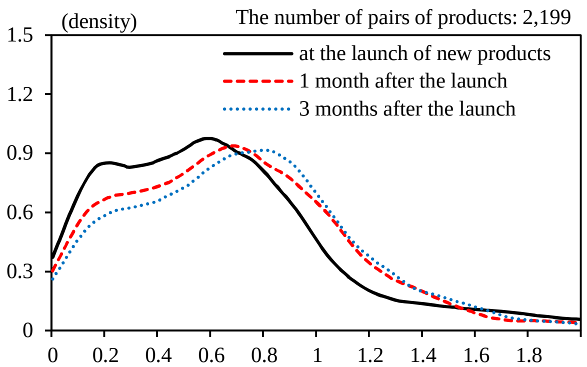


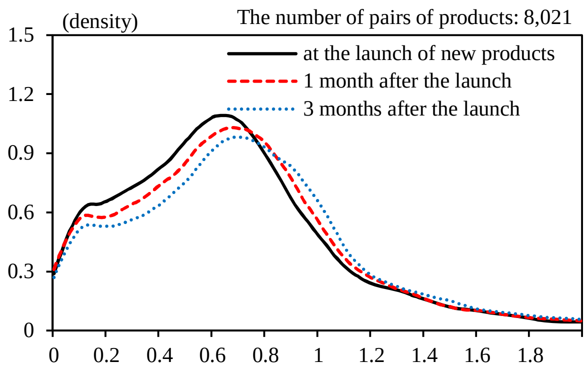
(Approximation using Kernel density graph)





(Shift in distribution of quality improvement ratio)

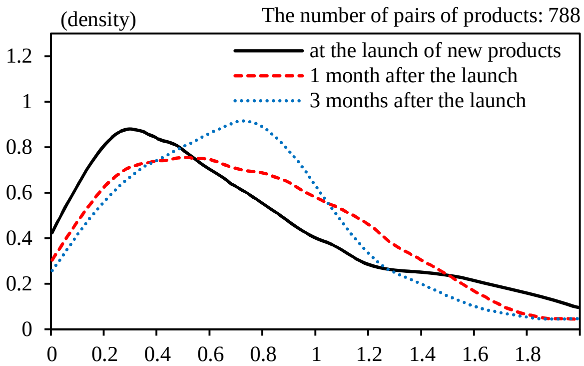




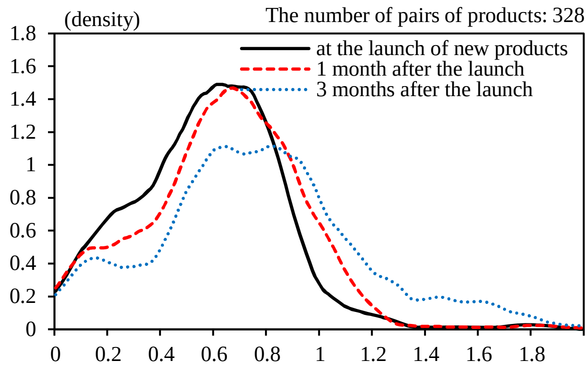
Note: A kernel density estimation enables to approximate a discrete probability distribution by tracing a smooth curve. In these figures, band width is decided by the *Silverman rule* and a kernel function is assumed to be the quadratic *Epanechnikov kernel*. Also, we conduct outlier processing by trimming the upper and lower 1 percent tails of matched pairs of new products and old products.

Appendix Figure B2 (*Levenshtein Distance*)
Distribution of Quality Improvement Ratios: Home Electrical Appliances

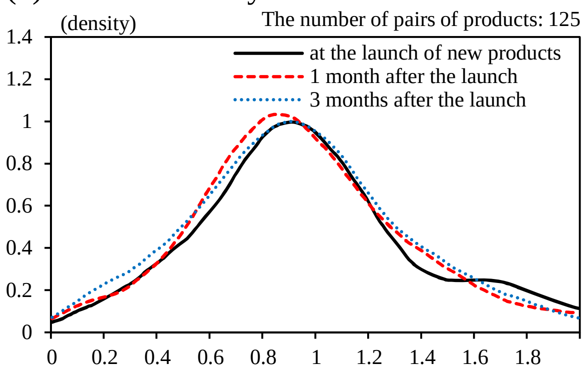
(1) Air conditioners



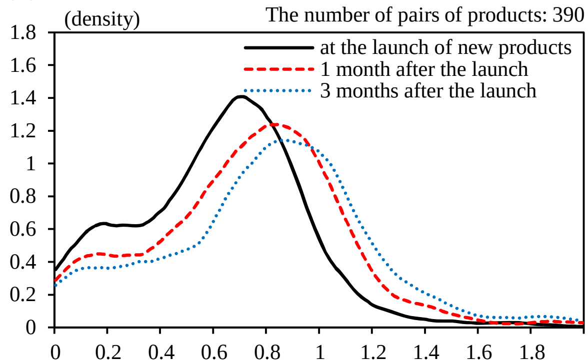
(2) Refrigerators and freezers



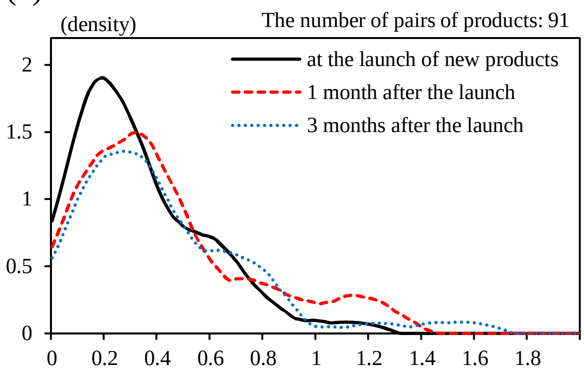
(3) Washers and dryers



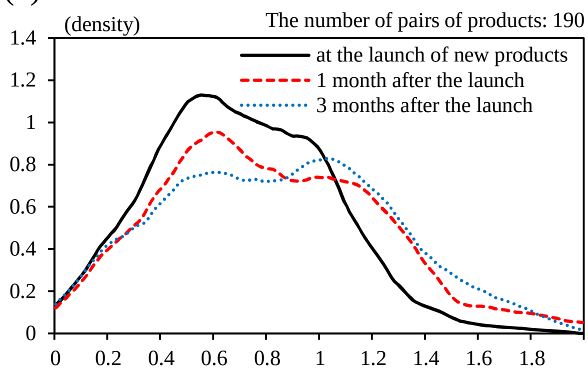
(4) Rice cookers



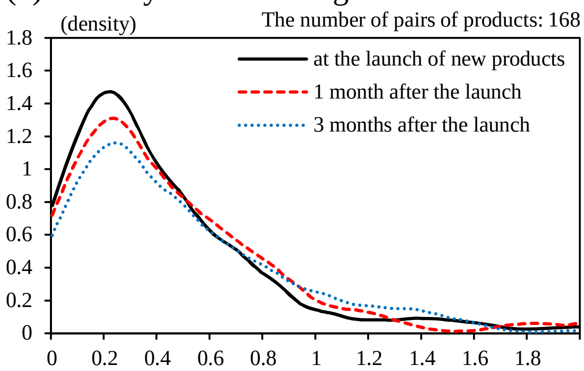
(5) Vacuum cleaners



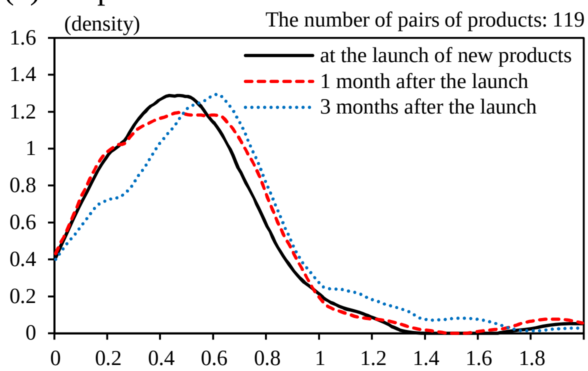
(6) Microwaves



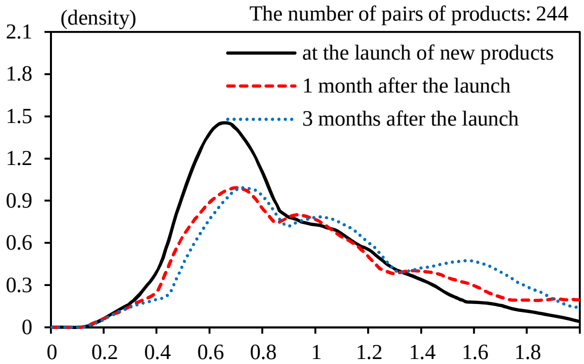
(7) Hair dryers and curling irons

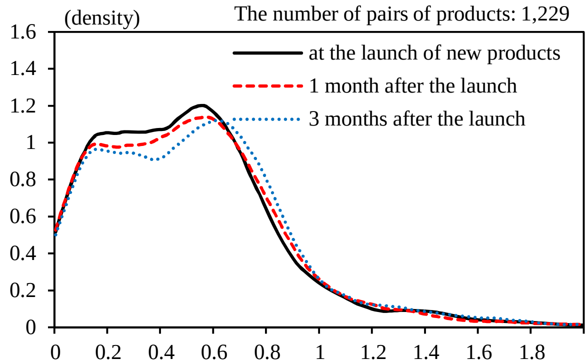


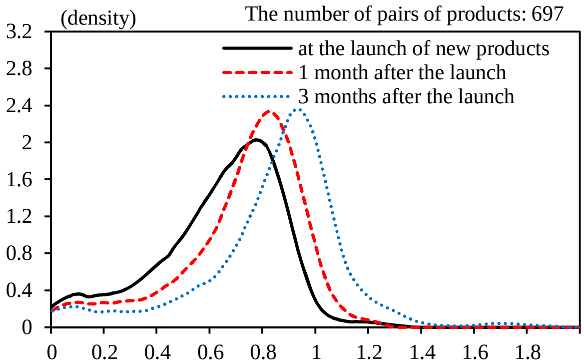
(8) Air purifiers

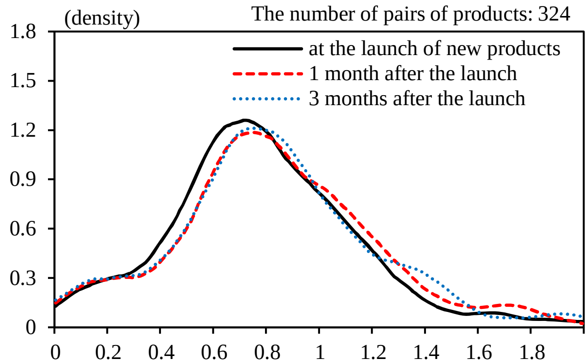


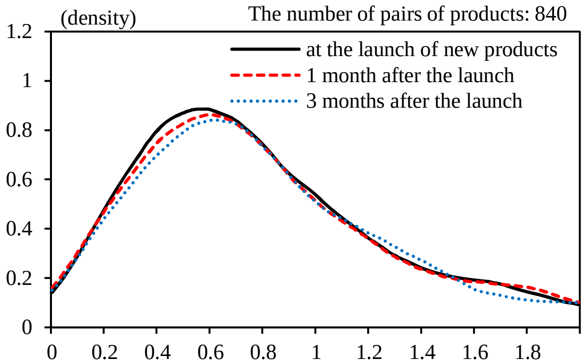
Appendix Figure B3 (*Levenshtein Distance*)
Distribution of Quality Improvement Ratios: Digital Consumer Electronics (1)

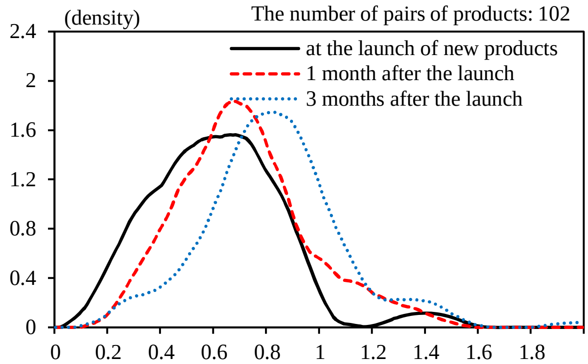
(1) GPS navigations


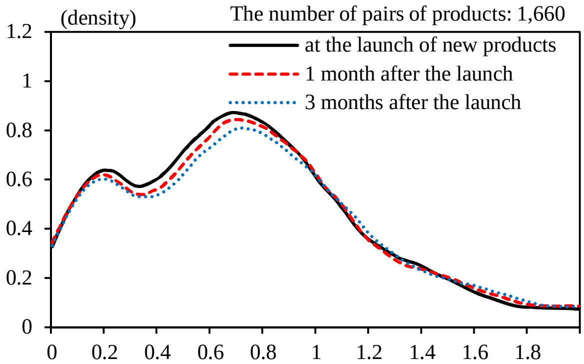
(2) External hard drives


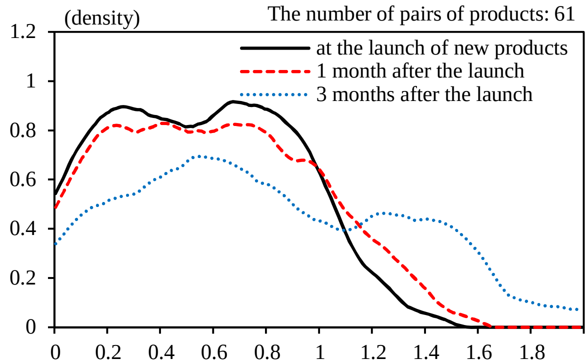
(3) LCD TVs


(4) LCD monitors


(5) Printers


(6) Blu-ray and DVD recorders


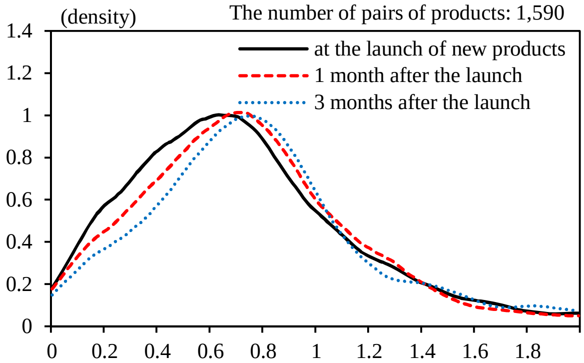
(7) Headphones


(8) Camcorders


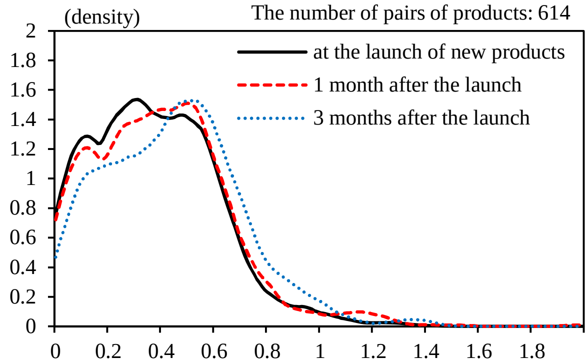
Appendix Figure B4 (*Levenshtein Distance*)

Distribution of Quality Improvement Ratios: Digital Consumer Electronics (2)

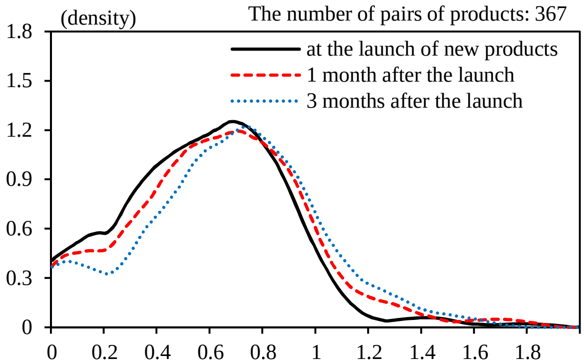
(9) Laptops



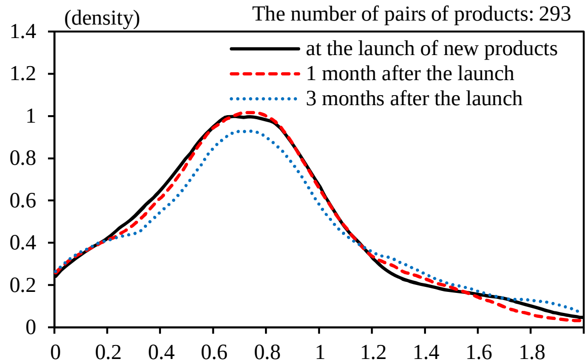
(10) Desktops



(11) Point-and-shoot cameras



(12) DSLR and mirrorless cameras



Mathematical Appendix 1
Approximation for Expected Value and Variance of the QIR

In this Mathematical Appendix, we derive an approximation for the expected value and variance of a function of two stochastic variables using the Taylor expansion. A function $f(\boldsymbol{X})$, where $\boldsymbol{X} = (x_1, x_2)^T$, can be approximated as follows by the second-order Taylor expansion around $\boldsymbol{\theta}$, the expected value of $\boldsymbol{X}$.

$$f(\boldsymbol{X}) \approx f(\boldsymbol{\theta}) + f_1'(\boldsymbol{\theta})(x_1 - \theta_1) + f_2'(\boldsymbol{\theta})(x_2 - \theta_2)$$
$$+\frac{1}{2}\{f_{11}''(\boldsymbol{\theta})(x_1 - \theta_1)^2 + 2f_{12}''(\boldsymbol{\theta})(x_1 - \theta_1)(x_2 - \theta_2) + f_{22}''(\boldsymbol{\theta})(x_2 - \theta_2)^2\}$$
$$\text{where} \quad f_i'(\boldsymbol{X}) = \frac{\partial f(\boldsymbol{X})}{\partial x_i}, \quad f_{ij}''(\boldsymbol{X}) = \frac{\partial^2 f(\boldsymbol{X})}{\partial x_i \partial x_j}$$

In this case, the expected value and variance of $f(\boldsymbol{X})$ are given by

$$\mathrm{E}[f(\boldsymbol{X})] \approx \mathrm{E}[f(\boldsymbol{\theta})] + \mathrm{E}[f_1'(\boldsymbol{\theta})(x_1 - \theta_1)] + \mathrm{E}[f_2'(\boldsymbol{\theta})(x_2 - \theta_2)]$$
$$+\frac{1}{2}\{\mathrm{E}[f_{11}''(\boldsymbol{\theta})(x_1 - \theta_1)^2] + 2\mathrm{E}[f_{12}''(\boldsymbol{\theta})(x_1 - \theta_1)(x_2 - \theta_2)] + \mathrm{E}[f_{22}''(\boldsymbol{\theta})(x_2 - \theta_2)^2]\}$$
$$= f(\boldsymbol{\theta}) + \frac{1}{2}f_{11}''(\boldsymbol{\theta})\mathrm{Var}(x_1) + f_{12}''(\boldsymbol{\theta})\mathrm{Cov}(x_1, x_2) + \frac{1}{2}f_{22}''(\boldsymbol{\theta})\mathrm{Var}(x_2) \quad \text{(A1)}$$

$$\mathrm{Var}[f(\boldsymbol{X})] = \mathrm{E}[(f(\boldsymbol{X}) - \mathrm{E}[f(\boldsymbol{X})])^2]$$
$$\approx \mathrm{E}[\{f_1'(\boldsymbol{\theta})(x_1 - \theta_1)\}^2] + \mathrm{E}[2\{f_1'(\boldsymbol{\theta})(x_1 - \theta_1)\}\{f_2'(\boldsymbol{\theta})(x_2 - \theta_2)\}]$$
$$+ \mathrm{E}[\{f_2'(\boldsymbol{\theta})(x_2 - \theta_2)\}^2]$$
$$= \{f_1'(\boldsymbol{\theta})\}^2\mathrm{Var}(x_1) + 2\{f_1'(\boldsymbol{\theta})f_2'(\boldsymbol{\theta})\}\mathrm{Cov}(x_1, x_2) + \{f_2'(\boldsymbol{\theta})\}^2\mathrm{Var}(x_2) \quad \text{(A2)}$$

By substituting $f(\boldsymbol{X}) = x_1/x_2$ and $\boldsymbol{\theta} = (\theta_1, \theta_2)^T = (\mathrm{E}(x_1), \mathrm{E}(x_2))^T$, the equations (A1) and (A2) can be transformed into the following expressions:

$$\mathrm{E}\left(\frac{x_1}{x_2}\right) \approx \frac{\mathrm{E}(x_1)}{\mathrm{E}(x_2)} + \frac{\mathrm{E}(x_1)}{\mathrm{E}(x_2)^3}\mathrm{Var}(x_2) - \frac{\mathrm{Cov}(x_1, x_2)}{\mathrm{E}(x_2)^2} \quad \text{(A3)}$$

$$\mathrm{Var}\left(\frac{x_1}{x_2}\right) \approx \left(\frac{\mathrm{E}(x_1)}{\mathrm{E}(x_2)}\right)^2 \left(\frac{\mathrm{Var}(x_1)}{\mathrm{E}(x_1)^2} + \frac{\mathrm{Var}(x_2)}{\mathrm{E}(x_2)^2} - \frac{2\mathrm{Cov}(x_1, x_2)}{\mathrm{E}(x_1)\mathrm{E}(x_2)}\right) \quad \text{(A4)}$$

In the above-mentioned equations (A3) and (A4), x_1 is regarded as the quality difference between new products and old products (Γ), and x_2 as the price difference (Δ_τ). We thus obtain the approximate expression for the expected value and variance of the QIR (μ_τ) as described in the main text. ■

Mathematical Appendix 2
Changes of Expected Value and Variance of the QIR with Elapse of Time

In this Mathematical Appendix, we verify the sufficient condition that the expected value and variance of the QIR between new products and old products are increases in time τ. We have obtained the approximate expressions for the expected value and variance of the QIR in the previous Mathematical Appendix.

$$\mathrm{E}(\mu_\tau) = \mathrm{E}\left(\frac{\Gamma}{\Delta_\tau}\right) \approx \frac{\mathrm{E}(\Gamma)}{\mathrm{E}(\Delta_\tau)} + \frac{\mathrm{E}(\Gamma)}{\mathrm{E}(\Delta_\tau)^3}\sigma(\Delta_\tau)^2 - \frac{\rho_{\Gamma,\Delta}\sigma(\Gamma)\sigma(\Delta_\tau)}{\mathrm{E}(\Delta_\tau)^2} \quad \text{(B1)}$$

$$\mathrm{Var}(\mu_\tau) = \mathrm{Var}\left(\frac{\Gamma}{\Delta_\tau}\right) \approx \left(\frac{\mathrm{E}(\Gamma)}{\mathrm{E}(\Delta_\tau)}\right)^2 \left(\frac{\sigma(\Gamma)^2}{\mathrm{E}(\Gamma)^2} + \frac{\sigma(\Delta_\tau)^2}{\mathrm{E}(\Delta_\tau)^2} - \frac{2\rho_{\Gamma,\Delta}\sigma(\Gamma)\sigma(\Delta_\tau)}{\mathrm{E}(\Gamma)\mathrm{E}(\Delta_\tau)}\right) \quad \text{(B2)}$$

where $\rho_{\Gamma,\Delta}$ represents the correlation coefficient between Γ and Δ_τ and $\sigma(\cdot)$ represents standard deviation. First, we show the condition that the expected value of the QIR increases with the elapse of time. When the QIR is close to the center of the Taylor expansion, the second and the third terms on the right-hand side of the equation (B1) are much smaller than the first term, so that the equation (B1) can be modified as follows:

$$\mathrm{E}(\mu_\tau) = \mathrm{E}\left(\frac{\Gamma}{\Delta_\tau}\right) \approx \frac{\mathrm{E}(\Gamma)}{\mathrm{E}(\Delta_\tau)}$$

Since $\mathrm{E}(\Gamma)$ is constant in time variable τ while $\mathrm{E}(\Delta_\tau)$ decreases in τ, the expected value of the QIR $\mathrm{E}(\mu_\tau)$ increases in τ.[b]

Next, we derive the condition that the variance of the QIR is increasing with the elapse of time. By transforming the formula (B2) and defining functions $f(\Delta_\tau)$ and $g(\Delta_\tau)$, we obtain the following approximation:

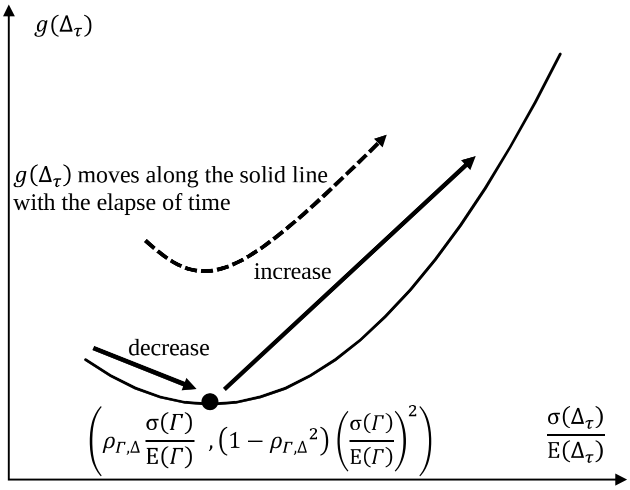
$$\mathrm{Var}(\mu_\tau) \approx \left(\frac{\mathrm{E}(\Gamma)}{\mathrm{E}(\Delta_\tau)}\right)^2 \left(\left[\frac{\sigma(\Delta_\tau)}{\mathrm{E}(\Delta_\tau)} - \rho_{\Gamma,\Delta}\frac{\sigma(\Gamma)}{\mathrm{E}(\Gamma)}\right]^2 + \left(1-{\rho_{\Gamma,\Delta}}^2\right)\left(\frac{\sigma(\Gamma)}{\mathrm{E}(\Gamma)}\right)^2\right)$$
$$= f(\Delta_\tau)\cdot g(\Delta_\tau)$$

$$\text{where}\quad f(\Delta_\tau) \equiv \left(\frac{\mathrm{E}(\Gamma)}{\mathrm{E}(\Delta_\tau)}\right)^2,\quad g(\Delta_\tau) \equiv \left[\frac{\sigma(\Delta_\tau)}{\mathrm{E}(\Delta_\tau)} - \rho_{\Gamma,\Delta}\frac{\sigma(\Gamma)}{\mathrm{E}(\Gamma)}\right]^2 + \left(1-{\rho_{\Gamma,\Delta}}^2\right)\left(\frac{\sigma(\Gamma)}{\mathrm{E}(\Gamma)}\right)^2$$

[b] We assume that the expected value of the price difference is decreasing in τ keeping in mind that the average pricing pattern shows downward convex. On the other hand, the variance of the price difference is increasing in τ provided that the variance of product prices is increasing in τ and the correlation coefficient of prices between new products and old products is sufficiently small. Here, we ignore the variance of the gap in launch dates between new products and old products and the price difference at the time of launching the former. Under particular circumstances, the above mentioned approximation retains the potential of impairing its accuracy.

As we stated before, the expected value of the quality difference $\mathrm{E}(\Gamma)$ is constant in τ and the expected value of the price difference $\mathrm{E}(\Delta_\tau)$ decreases in τ so that $f(\Delta_\tau)$ increases in τ.

Finally, let us focus on the geometric representation of $g(\Delta_\tau)$. The function $g(\Delta_\tau)$ is quadratic in $\sigma(\Delta_\tau)/\mathrm{E}(\Delta_\tau)$, and the relationship between $g(\Delta_\tau)$ and $\sigma(\Delta_\tau)/\mathrm{E}(\Delta_\tau)$ can be depicted as follows:



Given that $\sigma(\Delta_\tau)/\mathrm{E}(\Delta_\tau)$ is increasing in τ, the value of $g(\Delta_\tau)$ would move along the solid line in the upper graph from left to right with the elapse of time. If the value of $\sigma(\Delta_\tau)/\mathrm{E}(\Delta_\tau)$ is greater than that of $\sigma(\Delta_\tau)/\mathrm{E}(\Delta_\tau)$-coordinate of the vertex at the launch of the new products, i.e.,

$$\frac{\sigma\left(\Delta_{\tau|\tau=0}\right)}{\mathrm{E}\left(\Delta_{\tau|\tau=0}\right)} \geq \rho_{\Gamma,\Delta}\,\frac{\sigma(\Gamma)}{\mathrm{E}(\Gamma)} \tag{B3}$$

then $g(\Delta_\tau)$ obviously increases in τ. The condition (B3) implies that the coefficient of variation of the price difference is greater than that of the quality difference or the correlation coefficient between the price difference and quality difference is small.[c]

Inequality (B3) is one of the sufficient conditions which ensure that the variance of the QIR is increasing with the elapse of time.[d] ■

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[c] We regard the correlation coefficient $\rho_{\Gamma,\Delta}$ between the quality difference Γ and the price difference Δ_τ as constant in time, assuming the range of fluctuation is very small.

[d] Provided that the equation (B3) does not hold, then the value of $\sigma(\Delta_\tau)/\mathrm{E}(\Delta_\tau)$ is smaller than that of $\rho_{\Gamma,\Delta}\cdot\sigma(\Gamma)/\mathrm{E}(\Gamma)$ and the function $g(\Delta_\tau)$ could be decreasing in τ. In this case, the inequality $f'(\Delta_\tau)g(\Delta_\tau)+f(\Delta_\tau)g'(\Delta_\tau)>0$ would be a necessary and sufficient condition to guarantee that the variance of the QIR is increasing in τ.