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Effects of the Entry and Exit of Products on Price Indexes

Naohito Abe, Noriko Inakura, and Akiyuki Tonogi*

Abstract

This study analyzes the effects of product turnover for price measurements. In addition to variety effects, we consider the effects of the price differentials between new and incumbent products. The decomposition of a unit value price index (UVPI) into price change effects, substitution effects, and turnover/new product effects reveals the magnitude and sources of differences between the UVPI and the Cost of Living Indexes with variety effects. Using a large-scale scanner data, we find that the product turnover effects that reflect the price gap between new and old goods are quantitatively important when constructing a general price level index.

JEL Classification: C43, D12, E31

Keywords: Price Index, Cost of Living Index, Unit Value Price, POS Data

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Introduction

Establishing how the entry and exit of commodities affect consumer price indexes (CPIs) as well as cost of living indexes (COLIs) is a serious econometric problem. New products are introduced into markets almost daily, and, accordingly, a number of goods disappear on an almost daily basis. However, most economic indicators of prices, including official CPIs, are based on fixed bundles of commodities. Therefore, many newly introduced goods are neglected by the official statistics unless the new products account for a significant market share.

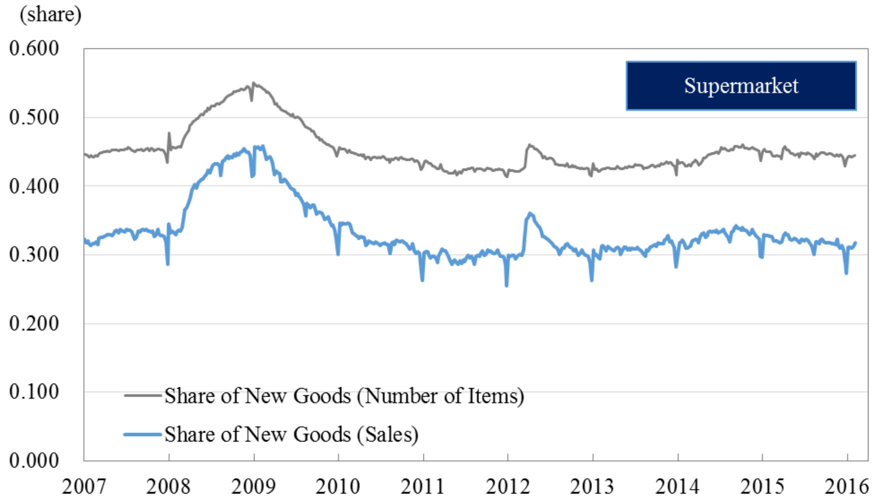

Figure 1: Product Appearance Rate

Notes: We define new goods as those goods for sale in the current period that were not available during the same week one year before. “Share of New Goods (Sales)” is the share of sales of new goods in total sales at a store in a week. “Share of New Goods (Number of Items)” is the share of new goods in the total number of items at a store in a week. When constructing shares, we calculate the shares at store level and then aggregate them over stores.

Figure 1 shows the weekly appearance rate of new products at supermarkets from our point-of-sales (POS) data.[1] More precisely, it shows the share, within total products, of the products that did not exist during the same week in the previous year, in terms of both the number of items and the proportion of sales. Measured by sales, new products account for about 35% of all products, whereas, in terms of the number of items, new products occupy more than 40% of the total sales.[2] Accordingly, by limiting the product bundle to products that have been available in the market for more than one year, a significant quantity of sales information is neglected.

Although official CPIs are based on a limited number of products, most economic data, including consumer expenditure and company sales data, cover all products that are traded. In other words, the price index is based largely on continuing goods, whereas expenditure and sales data include new goods that have just entered markets. This divergence in the product space between expenditure and the price index could cause serious inconsistency when constructing "real" economic variables if new goods are priced differently to incumbent goods.

The treatment of new products has been one of the most important issues in constructing price indexes. In the long history of price index theory, commencing with the seminal works of Fisher (1922), almost all of the index formula considered require at least two or more price data at distinct times or places so that we can calculate the price relatives, the ratio of the prices for the same commodity at two different times or places. Quite obviously, without multiple observations of prices, it is impossible to construct most of the well-known price indexes, including the Laspeyres and Fisher indexes. One of the commonly adopted approaches for handling newly appeared or disappeared goods is to create hypothetical price data.[3] If we have a complete set of information about

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[1] Section 4 describes the POS data in detail.

[2] Figure 1 treats goods with identical commodity codes (the Japanese Article Number) sold at different stores as different commodities. Therefore, the product appearance rate does not necessarily correspond to the appearance rate of newly released products from manufacturers.

[3] See *Consumer Price Index Manual: Theory and Practice* (2004, Chapter 8) by the International Labor Organization, the Organisation for Economic Co-operation and

commodity characteristics that affect consumers' welfare, it is possible to employ a hedonic approach to construct hypothetical price data. However, in most cases, the available information on product characteristics is far from complete. In practice, simpler methods such as the overlap approach are adopted for most product categories when calculating price indexes. Although the overlap approach is easy to implement, we need to assume that newly appeared goods have the same price dynamics as incumbent goods. Unfortunately, this is not the case.

Figure 2 compares the changes in prices of new and incumbent products. The line shows the relative (unit) price of newly introduced cup noodles compared with the average price of incumbent cup noodles. Soon after their introduction, the price of the new cup noodles tends to be about 20% higher than the price of the incumbent goods.[4] That is, as this example indicates, prices of new goods often exceed prices of incumbent goods.

From **Figure 2**, we can observe that: (1) new goods are priced differently from incumbent goods; and (2) the dynamic price paths for new goods are different from those of the incumbent goods. These two observations, together with the quantitative importance of new goods depicted in **Figure 1**, strongly suggest that entry and exit of commodities should be considered seriously when constructing a general price index. This study addresses this issue.[5]

Development, the Statistical Office of the European Communities, the United Nations, the International Bank for Reconstruction and Development, and the World Bank.

[4] Pricing patterns over product life cycles and their relationships to price indexes are an active research area. For example, see Balk (2000), Klenow (2003), Bils (2009), and Melser and Syed (2013).

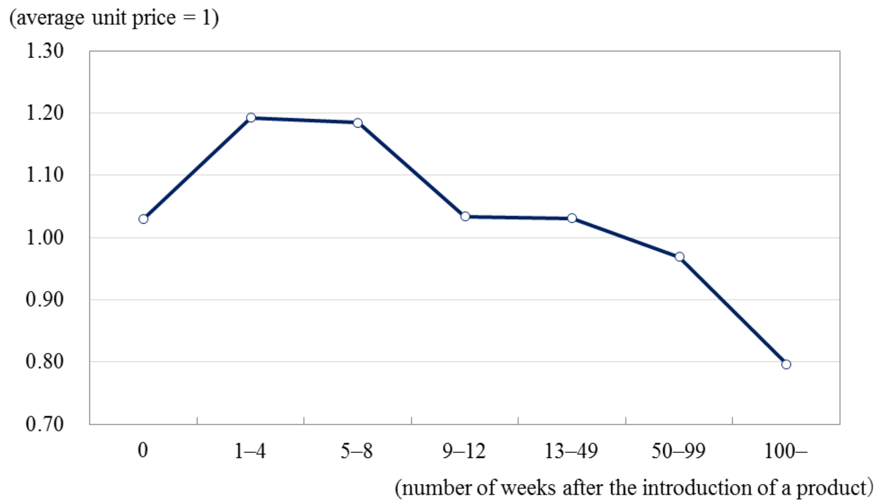

Figure 2: Differences in Unit Value Prices of New and Incumbent Cup Noodles

Notes: The relative price of items is based on cup noodles traded from September 2012 to December 2014. The horizontal axis shows the number of weeks that have passed since the introduction of the items. The vertical axis is the relative price of the items. The average price normalizes at unity. Relatively low prices in week zero might reflect bargain sales to promote new goods.

Another approach to considering goods that have recently appeared or disappeared when constructing price indexes is to use economic theory. Based on a constant elasticity of substitution (CES) aggregator function, Feenstra (1994) and Feenstra and Shapiro (2003) derive a formula for a COLI that captures the welfare effects of variety expansion. Broda and Weinstein (2010), also using the CES aggregator function, find that new goods cause significant "bias" in the price index. Variety expansion effects have become of increasing interest in many fields of economics, including international trade, economic growth, and business cycle research.[6] In the analyses by the authors mentioned above, the appearance of new goods affects consumers' welfare through a change in the total

[6] See Bernard, Redding, and Schott (2010), Bilbiie, Ghironi, and Melitz (2012), and Hamano (2013) for recent developments.

number of product varieties, not through price differentials between new and incumbent goods. Although the variety channel is certainly important, other effects, including the introduction of commodities with higher/lower prices or qualities, can have a major impact on consumer welfare and the general price level. For example, assume that a firm replaces its old product with a new product of the same quality but with a higher price. Ceteris paribus, consumers' welfare will decrease and the true COLIs will increase. However, as the total number of product varieties is unchanged, the COLIs constructed by Feenstra (1994) will remain unchanged, despite the fact that consumers' welfare decreases.

Rather than focusing on the variety expansion effects, the present study considers the effects on the price index of the price differentials between new products and incumbent products. More precisely, we construct a unit value price index (UVPI) that covers all products, including new goods. The change in the UVPI is decomposed into: (1) standard price change effects that are identical to the changes in the Laspeyres price indexes; (2) substitution effects within the continuing goods category that reflect changes in the share of commodities; and (3) turnover/new product effects that capture the contribution of the price differentials between new and incumbent goods. This decomposition is an extension of the previous studies by Silver (2009, 2010) and Diewert and Von der Lippe (2010), which consider continuing goods, but exclude our third effects, the turnover/new product effects.

If the differences in quality between new and existing goods are negligible, the price differentials between new and incumbent goods affect COLIs in a straightforward manner. On the other hand, if there are substantial changes in quality between the new and incumbent goods, the price differences will mainly be a reflection of the quality differences. In such a case, the third effects (the turnover/new product effects) can be offset by the differences in quality in terms of their impact on consumers' welfare. Unfortunately, without detailed information on product characteristics, it is impossible to identify the importance of quality differences. That is, the third effects tell us the two extreme cases. If price differences between new and incumbent goods are very small after controlling for quality differences, the sum of the first and second effects can be regarded as the unbiased estimates of the true CPI. On the other hand, if the newly appeared goods are of the same quality as the old goods, but have higher/lower prices, the third effects contain very important information on consumers' welfare that is not captured by the conventional price indexes based on continuing goods, or by the COLIs based on variety expansion effects. We suspect that the effects of the quality differentials between the new and incumbent goods lie between the two extreme cases. That is, our estimates of the UVPI with the turnover/new product effects provide upper limit estimates of the true CPI if the quality of the new goods is no worse than that of the incumbent goods.[7]

In the empirical part of this study, which is based on weekly scanner data collected in 4,000 retail stores across Japan, we show that a decomposition of the data into these three effects above reveals that the turnover/new product effects are generally nonnegligible. The effects became very large during 2007, 2008, and the period after 2014, so that the discrepancies between the UVPI and other price indexes and COLIs became significant. During these periods, input prices for companies increased because of the depreciation of the currency and the surge in material prices. Rather than increasing the tag price of incumbent goods, it is possible that companies introduced new goods of a similar quality and price to the old but of a smaller size or quantity to obscure the price increase. Section 6 discusses the relation between quality and price changes during those periods in detail.

The rest of the paper proceeds as follows. In Section 2, we review the COLIs with product turnover developed by Feenstra (1994) and Broda and Weinstein (2010) to inform our calculation of COLIs based on the POS data in a later section. Section 3 explains our UVPI and the decomposition of the UVPI into the three price change effects. Section 4 describes the scanner data used in this study. In Section 5, we compare and discuss the results of the UVPI and COLIs with product turnover and conventional price indexes. Section 6 discusses some cases of actual product turnover to illustrate the possible effects of quality differences. The final section concludes the paper.

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[7] It is also possible that new goods are lower quality and have higher prices than incumbent goods. In such a case, the turnover/new goods effect is lower than the true price effects.

I. Cost of Living Index with Product Turnover

The seminal work of Feenstra (1994) develops the concept of the COLI with product variety, based on the CES-type utility function. Broda and Weinstein (2010) extend the COLI to include the effects of brand variety. In this section, we review the COLIs developed by Feenstra (1994) and Broda and Weinstein (2010).

A. Feenstra's Cost of Living Index

We start by describing the CES utility function of the representative consumer. The upper level utility function, U_t, at time *t* is specified as follows:

$$U_t = \left(\sum_{g_t \in G} \beta_{g_t} \left(C_t^{g_t} \right)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}},$$

where $C_t^{g_t}$ is the aggregate consumption of product group $g_t \in G$, β_g is the weight of category g_t in the CES utility function, and G is the set of all product groups. Note that we allow the elements of each product group set, g_t, to vary over time. That is, in each group, new commodities could emerge and other goods disappear, so that the total number of commodities in the set g_t is not constant over time. σ is the CES across product groups for demand. The lower level of the utility function is:

$$C_t^{g_t} = \left(\sum_{i \in g_t} \alpha_i \left(q_t^i \right)^{\frac{\sigma_g-1}{\sigma_g}} \right)^{\frac{\sigma_g}{\sigma_g-1}},$$

where q_t^i is the consumption quantity of the individual goods index $i \in g_t$, and α_i is the weight of goods i in the CES aggregator. σ_g is the CES within product group g_t for demand.[8] Solving the optimization problem of the consumer, we obtain the unit cost function of $C_t^{g_t}$ as follows:

$$\frac{E(p_t, g_t)}{C_t^{g_t}} = \left(\sum\nolimits_{i \in g_t} \alpha_i^{\sigma} \left(p_t^i\right)^{1-\sigma_g}\right)^{\frac{1}{1-\sigma_g}},$$

where p_t is the vector of individual prices and p_t^i is the price of the individual goods index, $i \in g_t$. The COLI of product group g_t can be written as:

$$COLI\left(p_t, p_{t-y}, g_t, g_{t-y}\right) = \frac{E(p_t, g_t)}{E(p_{t-y}, g_{t-y})}.$$

Sato (1976) and Vartia (1976) show that the above COLI can be calculated without estimating the values of α_i and σ_g if the sets of individual product groups are the same between the current and base period: that is, if $g_t = g_{t-y} = g$. The exact price index, $PI_{SV}\left(p_t, p_{t-y}, g\right)$, can be formulated as follows:

$$\frac{E(p_t, g)}{E(p_{t-y}, g)} = \prod_{i \in g} \left(\frac{p_t^i}{p_{t-y}^i}\right)^{\phi_t^i(g)} \equiv PI_{SV}\left(p_t, p_{,t-y}, g\right),$$

where

$$\phi_t^i(g) = \frac{\left(\dfrac{w_t^i(g) - w_{t-y}^i(g)}{\ln\left(w_t^i(g)\right) - \ln\left(w_{t-y}^i(g)\right)}\right)}{\sum_{i \in g}\left(\dfrac{w_t^i(g) - w_{t-y}^i(g)}{\ln\left(w_t^i(g)\right) - \ln\left(w_{t-y}^i(g)\right)}\right)}, \text{and } w_t^i(g) = \frac{p_t^i q_t^i}{\sum_{i \in g} p_t^i q_t^i}.$$

It is possible to obtain the aggregate-level Sato–Vartia-type COLI, as follows:

$$PI_t^{\mathrm{SV}} = \prod_{g \in G} \left[PI_{SV}\left(p_t, p_{t-y}, g_{t,t-y}\right)\right]^{\phi_t^g},$$

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[8] To be precise, σ_g should be denoted as σ_{g_t} because the goods category varies over time. To keep the expression simple, we omit the subscript *t* from σ_{g_t}.

where

$$\phi_t^g = \frac{\left(\frac{w_t^g - w_{t-y}^g}{\ln(w_t^g) - \ln(w_{t-y}^g)}\right)}{\sum_{g\in G}\left(\frac{w_t^g - w_{t-y}^g}{\ln(w_t^g) - \ln(w_{t-y}^g)}\right)} \text{, where } w_t^g = \frac{\sum_{i\in g_{t,t-y}} p_t^i q_t^i}{\sum_{g\in G}\sum_{i\in g_{t,t-y}} p_t^i q_t^i}.$$

Based on Sato (1976) and Vartia (1976), Feenstra (1994) develops the concept of the COLI for the case in which sets of individual products are not the same between the current period and the base period: that is, $g_t \neq g_{t-y}$. Feenstra's COLI is defined as follows:

$$\frac{E(p_t, g_t)}{E(p_{t-y}, g_{t-y})} = PI_{SV}^g(p_t, p_{t-y}, g_{t,t-y})\left(\frac{\lambda_{gt}^{\mathrm{cr}}}{\lambda_{gt}^{\mathrm{bs}}}\right)^{\frac{1}{\sigma_g - 1}} \equiv P_F(p_t, p_{t-y}, g_t, g_{t-y}),$$

where

$$g_{t,t-y} = g_t \cap g_{t-y},$$

$$\lambda_{gt}^{\mathrm{cr}} = \frac{\sum_{i\in g_{t,t-y}} p_t^i q_t^i}{\sum_{i\in g_t} p_t^i q_t^i}, \lambda_{gt}^{\mathrm{bs}} = \frac{\sum_{i\in g_{t,t-y}} p_{t-y}^i q_{t-y}^i}{\sum_{i\in g_{t-y}} p_{t-y}^i q_{t-y}^i}.$$

The term $\lambda_{gt}^{\mathrm{cr}}$ denotes the sales share of the surviving goods between the current and base periods in the current period *t*, whereas $\lambda_{gt}^{\mathrm{bs}}$ is the sales share of surviving goods between the current and base periods in the base period, *t*–*y*. When the set of product groups changes, Feenstra's COLI becomes the product of the exact price index based on $g_{t,t-y}$ and the term $(\lambda_{gt}^{\mathrm{cr}}/\lambda_{gt}^{\mathrm{bs}})^{\frac{1}{\sigma_g - 1}}$, which is known as the group-level lambda ratio, adjusted by σ_g. Note that, unlike the Sato–Vartia-type COLI, to obtain the lambda ratio, we require information on the elasticity of substitution for demand within a group.

The aggregate-level COLI based on Feenstra (1994), PI_t^{F}, is given by the following expression:

$$PI_t^{\mathrm{F}} = \prod_{g\in G}\left[PI_{SV}\left(p_t, p_{t-y}, g_{t,t-y}\right)\left(\frac{\lambda_{gt}^{\mathrm{cr}}}{\lambda_{gt}^{\mathrm{bs}}}\right)^{\frac{1}{\sigma_g-1}}\right]^{\phi_t^g}.$$

B. Broda–Weinstein's Cost of Living Index

Based on Feenstra (1994), Broda and Weinstein (2010) extend the COLI by taking account of within-brand and across-brand variety. In other words, in addition to product variety effects, Broda and Weinstein (2010) consider brand expansion effects. Their COLI has three layers: brand-level, product group-level, and aggregate-level COLIs. The brands are the lower layer in the product groups. The set of brands that change over time is denoted as b_t, which is a subset of g_t.

The aggregate-level COLI based on Broda and Weinstein (2010), PI_t^{BW}, is defined as follows:

$$PI_t^{\mathrm{BW}} = \prod_{g_t\in G}\left\{\prod_{b\in g_t}\left[PI_{SV}\left(p_t, p_{t-y}, b_{t,t-y}\right)\left(\frac{\lambda_{bt}^{\mathrm{cr}}}{\lambda_{bt}^{\mathrm{bs}}}\right)^{\frac{1}{\sigma_{wb}(b)-1}}\right]^{\phi_t^{wb}(b)} \times\left(\frac{\lambda_{gt}^{\mathrm{cr}}}{\lambda_{gt}^{\mathrm{bs}}}\right)^{\frac{1}{\sigma_{ab}(g_t)-1}}\right\}^{\phi_t^{ab}(g_t)},$$

where $PI_{SV}\left(p_t, p_{t-y}, b_{t,t-y}\right)$ is the brand-level Sato–Vartia-type COLI. $\sigma_{wb}(b)$ is the substitution elasticity of demand within brands in brand b, and $\sigma_{ab}(b)$ is the substitution elasticity of demand across brands in product group g_t. $\left(\lambda_{bt}^{\mathrm{cr}}/\lambda_{bt}^{\mathrm{bs}}\right)^{\frac{1}{\sigma_{wb}(b)-1}}$ is the brand-level lambda ratio adjusted by $\sigma_{wb}(b)$, whereas $\left(\lambda_{gt}^{\mathrm{cr}}/\lambda_{gt}^{\mathrm{bs}}\right)^{\frac{1}{\sigma_{ab}(g)-1}}$ is the group-level lambda ratio adjusted by $\sigma_{ab}(g)$. The parameters, $\lambda_{bt}^{\mathrm{cr}}$, $\lambda_{bt}^{\mathrm{bs}}$, $\lambda_{gt}^{\mathrm{cr}}$, and $\lambda_{gt}^{\mathrm{bs}}$, are defined, respectively, as follows:

$$\lambda_{bt}^{\mathrm{cr}} = \frac{\sum_{i\in b_{t,t-y}} p_t^i q_t^i}{\sum_{i\in b_t} p_t^i q_t^i}, \lambda_{bt}^{\mathrm{bs}} = \frac{\sum_{i\in b_{t,t-y}} p_{t-y}^i q_{t-y}^i}{\sum_{i\in b_{t-y}} p_{t-y}^i q_{t-y}^i},$$

$$\lambda_{gt}^{\text{cr}} = \frac{\sum_{b\in g_{t,t-y}} \sum_{i\in b_{t,t-y}} p_t^i q_t^i}{\sum_{b\in g_t} \sum_{i\in b_t} p_t^i q_t^i}\ , \lambda_{gt}^{\text{bs}} = \frac{\sum_{i\in g_{t,t-y}} \sum_{i\in b_{t,t-y}} p_{t-y}^i q_{t-y}^i}{\sum_{i\in g_{t-y}} \sum_{i\in b_{t-y}} p_{t-y}^i q_{t-y}^i}.$$

$\phi_t^{wb}(b)$ and $\phi_t^{ab}(g)$ are defined, respectively, as follows:

$$\phi_t^{wb}(b) = \frac{\left(\frac{w_t^b - w_{t-y}^b}{\ln(w_t^b) - \ln(w_{t-y}^b)}\right)}{\sum_{b\in g}\left(\frac{w_t^b - w_{t-y}^b}{\ln(w_t^b) - \ln(w_{t-y}^b)}\right)}\ , \text{where } w_t^b = \frac{\sum_{i\in b_{t,t-y}} p_t^i q_t^i}{\sum_{b\in g} \sum_{i\in b_{t,t-y}} p_t^i q_t^i},$$

$$\phi_t^{ab}(g) = \frac{\left(\frac{\widetilde{w}_t^g - \widetilde{w}_{t-y}^g}{\ln(\widetilde{w}_t^g) - \ln(\widetilde{w}_{t-y}^g)}\right)}{\sum_{g\in G}\left(\frac{\widetilde{w}_t^g - \widetilde{w}_{t-y}^g}{\ln(\widetilde{w}_t^g) - \ln(\widetilde{w}_{t-y}^g)}\right)}\ , \text{where } \widetilde{w}_t^g = \frac{\sum_{b\in g_{t,t-y}} \sum_{i\in b_{t,t-y}} p_t^i q_t^i}{\sum_{g\in G} \sum_{b\in g_{t,t-y}} \sum_{i\in b_{t,t-y}} p_t^i q_t^i}.$$

To calculate the Broda–Weinstein COLI, we need to estimate the elasticities of substitution for demand both within and across brands in a category from the data.

II. Decomposition of the Unit Value Price Index

In this section, we define the UVPI and demonstrate the procedure for decomposing changes in the rate of the UVPI into the effects of a standard product-level price change within continuing goods, the substitution effects within continuing goods, and the turnover/new product effects. That is, this section presents and discusses a formula that describes the inflation rate of the UVPI as the weighted sum of the three effects, as follows:

$$\begin{aligned}&\textbf{Inflation Rate of Unit Value Price Index}\\ &\qquad = \mathbf{a_1} \times \textbf{Price Change Effects} + \mathbf{a_2} \times \textbf{Substitution Effects}\\ &\qquad + \mathbf{a_3} \times \textbf{Turnover Effects} + \mathbf{a_4} \times \textbf{Cross Term}.\end{aligned}$$

A. Unit Value Price Index as a Cost of Living Index

Assume that the representative consumer obtains utility from the total sum of consumption volume, that is, all the consumption goods are perfect substitutes in each category. For example, although a 500 ml orange juice package and a 1000 ml orange juice package of the same brand are distinguished from the perspective of their Universal Product Codes, their contents are virtually the same. We assume that the consumption of these two orange juice packages gives the same utility level to a consumer as does the consumption of a 1500 ml package of orange juice of the same brand. Under the assumption of perfect substitution within the category, we can measure the price level of one category as the UVPI.

More concretely, we assume that the utility function of the representative consumer has the following two layers:

$$U_t = \left(\sum_{g_t \in G} \beta_g \left(C_t^{g_t} \right)^{\frac{\sigma - 1}{\sigma}} \right)^{\frac{\sigma}{\sigma - 1}},$$

$$C_t^{g_t} = \sum_{i \in g_t} v^i q_t^i,$$

where v^i is the volume of product i.

Then, the unit cost of product group $P_t^U(g)$ can be written as:

$$P_t^U(g) = \frac{E(p_t, q_t, v, g_t)}{C_t^{g_t}} = \sum_{i \in g_t} \left(\frac{v^i q_t^i}{\sum_{i \in g_t} v^i q_t^i} \right) \frac{p_t^i}{v^i},$$

where v is a vector of v^i, $i \in g$.

The UVPI is defined as:

$$PI_U\left(p_t, p_{t-y}, q_t, q_{t-y}, g_t, g_{t-y}\right) = \frac{P_t^U(g_t)}{P_{t-y}^U(g_{t-y})}.$$

The aggregate-level COLI is given by the following expression:

$$PI_t^{\mathrm{U}} = \prod_{g \in G} \left[PI_U\left(p_t, p_{t-y}, q_t, q_{t-y}, g_t, g_{t-y}\right) \right]^{\phi_t^{gu}},$$

where

$$\phi_t^{gu} = \frac{\left(\frac{w_t^{gu} - w_{t-y}^{gu}}{\ln\left(w_t^{gu}\right) - \ln\left(w_{t-y}^{gu}\right)}\right)}{\sum_{g\in G}\left(\frac{w_t^{gu} - w_{t-y}^{gu}}{\ln\left(w_t^{gu}\right) - \ln\left(w_{t-y}^{gu}\right)}\right)} \text{ and } w_t^{gu} = \frac{\sum_{i\in g_t} p_t^i q_t^i}{\sum_{g\in G}\sum_{i\in g_t} p_t^i q_t^i}.$$

B. New Goods, Old Goods, and Continuing Goods

To capture the effects of the changes in the product space, first, we classify all products in category g_t into three groups: (1) new goods, (2) old goods, and (3) continuing goods. Consider two periods, the current period t and the base period $t - y$, where y is a fixed time interval, such as one year. An individual product i is defined as a "new good" in period t if the product exists in period t but not in period $t - y$. Similarly, an individual product i is defined as an "old good" in period t if the product does not exist in period t but exists in period $t - y$. An individual product i is defined as a "continuing good" in period t if the product exists in both period t and period $t - y$. g_t^N, g_t^O, and $g_{t,t-y}$ denote the set of new goods, the set of old goods, and the set of continuing goods, respectively, in category g in period t. By construction, the set of available goods at time t in category g, g_t is a union of the new goods and continuing goods: that is, g_t=$g_t^N \cup g_{t,t-y}$. Similarly, the continuing goods can be defined as the intersection of g_t and g_{t-y}: that is, $g_{t,t-y} = g_t \cap g_{t-y}$. It is straightforward to derive the following relations:

$$g_t^N = g_t \backslash g_{t,t-y},$$

$$g_t^O = g_{t-y} \backslash g_{t,t-y}.$$

C. Unit Value Price Indexes for New Goods, Old Goods, and Continuing Goods

Let us denote the quantity and price of item i sold in period t as q_t^i and p_t^i, respectively. v^i denotes the volume of product i. The total unit value price of category g in period t, $P_t^U(g)$, can be expressed as the weighted sum of the unit value price of continuing goods, $P_t^{UC}(g)$, and that of new goods, $P_t^{UN}(g)$.

$$P_t^U(g) = \sum_{i\in g_t}\left(\frac{v^i q_t^i}{\sum_{i\in g_t} v^i q_t^i}\right)\frac{p_t^i}{v^i}$$

$$= \left(\frac{\sum_{i\in g_{t,t-y}} v^i q_t^i}{\sum_{i\in g_t} v^i q_t^i}\right)\sum_{i\in g_{t,t-y}}\left(\frac{v^i q_t^i}{\sum_{i\in g_{t,t-y}} v^i q_t^i}\right)\frac{p_t^i}{v^i} + \left(\frac{\sum_{i\in g_t^N} v^i q_t^i}{\sum_{i\in g_t} v^i q_t^i}\right)\sum_{i\in g_t^N}\left(\frac{v^i q_t^i}{\sum_{i\in g_t^N} v^i q_t^i}\right)\frac{p_t^i}{v^i}$$

$$= w_t^C(g)P_t^{UC}(g) + w_t^N(g)P_t^{UN}(g),$$

where

$$w_t^C\,(g) = \frac{\sum_{i\in g_{t,t-y}} v^i q_t^i}{\sum_{i\in g_t} v^i q_t^i}, w_t^N(g) = \frac{\sum_{i\in g_t^N} v^i q_t^i}{\sum_{i\in g_t} v^i q_t^i},$$

$$P_t^{UC}(g) = \sum_{i\in g_{t,t-y}}\left(\frac{v^i q_t^i}{\sum_{i\in g_{t,t-y}} v^i q_t^i}\right)\frac{p_t^i}{v^i}, \text{and } P_t^{UN}(g) = \sum_{i\in g_t^N}\left(\frac{v^i q_t^i}{\sum_{i\in g_t^N} v^i q_t^i}\right)\frac{p_t^i}{v^i}.$$

Similarly, we can construct the UVPI in period $t - y$, $P_{t-y}^U(g)$, as the weighted sum of the unit value prices of continuing goods, $P_{t-y}^{UC}(g)$, and of old goods, $P_{t-y}^{UO}(g)$.

$$P_{t-y}^U(g) \equiv \sum_{i\in g_{t-y}}\left(\frac{v^i q_{t-y}^i}{\sum_{i\in g_{t-y}} v^i q_{t-y}^i}\right)\frac{p_{t-y}^i}{v^i}$$

$$= \left(\frac{\sum_{i\in g_{t,t-y}} v^i q_{t-y}^i}{\sum_{i\in g_{t-y}} v^i q_{t-y}^i}\right)\sum_{i\in g_{t,t-y}}\left(\frac{v^i q_{t-y}^i}{\sum_{i\in g_{t,t-y}} v^i q_{t-y}^i}\right)\frac{p_{t-y}^i}{v^i}$$
$$+ \left(\frac{\sum_{i\in g_t^O} v^i q_{t-y}^i}{\sum_{i\in g_{t-y}} v^i q_t^i}\right)\sum_{i\in g_t^O}\left(\frac{v^i q_{t-y}^i}{\sum_{i\in g_t^O} v^i q_{t-y}^i}\right)\frac{p_{t-y}^i}{v^i}$$

$$= w_{t-y}^C(g)P_{t-y}^{UC}(g) + w_{t-y}^O(g)P_{t-y}^{UO}(g),$$

where

$$w_{t-y}^C(g) = \frac{\sum_{i\in g_{t,t-y}} v^i q_{t-y}^i}{\sum_{i\in g_{t-y}} v^i q_{t-y}^i}, w_{t-y}^O(g) = \frac{\sum_{i\in g_t^O} v^i q_{t-y}^i}{\sum_{i\in g_{t-y}} v^i q_{t-y}^i},$$

$$P_{t-y}^{UC}(g) = \sum_{i \in g_{t,t-y}} \left(\frac{v^i q_{t-y}^i}{\sum_{i \in g_{t,t-y}} v^i q_{t-y}^i} \right) \frac{p_{t-y}^i}{v^i}, \text{and } P_{t-y}^{UO}(g) = \sum_{i \in g_t^O} \left(\frac{v^i q_{t-y}^i}{\sum_{i \in g_t^O} v^i q_{t-y}^i} \right) \frac{p_{t-y}^i}{v^i}.$$

D. Decomposition into Price Change, Substitution, and Turnover/New Goods Effects

The inflation rate of the UVPI can be written as follows:

$$\frac{P_t^U(g) - P_{t-y}^U(g)}{P_{t-y}^U(g)}$$
$$= \left(\frac{P_{t-y}^{UC}(g)}{P_{t-y}^U(g)} \right) \frac{w_t^C(g) P_t^{UC}(g) - w_{t-y}^C(C) P_{t-y}^{UC}(g)}{P_{t-y}^{UC}(g)}$$
$$+ \left(\frac{P_{t-y}^{UO}(g)}{P_{t-y}^U(g)} \right) \frac{w_t^N(g) P_t^{UN}(g) - w_{t-y}^O(g) P_{t-y}^{UO}(g)}{P_{t-y}^{UO}(g)}.$$

Using the formula for the Laspeyres price index, $\pi_t^{LC}(g)$, the substitution effect among continuing goods, $\phi_{\mathrm{t}}^{UC}(g)$,[9] and the effects of product turnover, we can express the rate of change of the UVPI as the weighted sum of the three price effects and the cross-term:[10]

$$\frac{P_t^U(g) - P_{t-y}^U(g)}{P_{t-y}^U(g)}$$
$$= \left(\frac{P_{t-y}^{UC}(g)}{P_{t-y}^U(g)} \right) w_{t-y}^C(g) \pi_t^{LC}(g) + \left(\frac{P_{t-y}^{UC}(g)}{P_{t-y}^U(g)} \right) w_{t-y}^C(g) \phi_t^{UC}(g)$$
$$+ \frac{w_{t-y}^O(g)\left(P_t^{UC}(g) - P_{t-y}^{UO}(g)\right) + w_t^N(g)(P_t^{UN}(g) - P_t^{UC}(g))}{P_{t-y}^U(g)}$$
$$+ \left(\frac{P_{t-y}^{UC}(g)}{P_{t-y}^U(g)} \right) w_{t-y}^C(g) \phi_t^{UC}(g) \pi_t^{UC}(g),$$

where $\pi_t^{UC} = \left(P_t^{UC}(g) - P_{t-y}^{UC}(g)\right) / P_{t-y}^{UC}(g)$, and

[9] We follow the definition of Diewert and Von der Lippe (2010) in relation to the substitution effect. This substitution effect can be written as the covariance between the change in the volume share and relative prices. See A2 in Appendix A for details.
[10] See Appendix A for the derivation.

$$\phi_t^{UC}(g) = \frac{\sum_{i \in g_{t,t-y}} p_t^i [s_t^i - s_{t-y}^i]}{\sum_{i \in g_{t,t-y}} \left[\frac{v^i q_t^i}{\sum_{i \in g_{t,t-y}} v^i q_t^i} \times \frac{p_t^i}{v^i} \right]}, s_t^i = \frac{v^i q_t^i}{\sum_{i \in g_{t,t-y}} v^i q_t^i}.$$

The first term on the right-hand side (RHS) of (5) is the standard price change effect measured by the Laspeyres formula. Note that if there were no product turnover, we would obtain $P_{t-y}^{\mathrm{UC}}(g) = P_{t-y}^{U}(g)$ and $w_{t-y}^{C}(g) = 1$. Thus, the first term would be equal to the standard rate of price change, $\pi_t^{LC}(g)$. The second term represents the substitution effects within the continuing goods category. If this term were negative, a product with a relatively lower unit value price would increase its volume share. That is, the substitution effect captures the degree to which demand shifts in response to the differences in relative prices. The third term shows the contribution of product turnover to the UVPI. The numerator of the third term is the weighted sum of the price differential between (1) new goods and continuing goods, and (2) continuing goods and disappearing goods. Note that $w_{t-y}^{O}(g)$ is the ratio of disappearing goods within the total volume of goods sold in period $t-y$, and $P_t^{UC}(g) - P_{t-y}^{UO}(g)$ shows the differences between the unit value prices of continuing goods and old goods. In addition, note that $w_t^N(g)$ is the ratio of new goods to the total volume of goods sold in period t, and that $P_t^{UN}(g) - P_t^{UC}(g)$ shows the difference between the unit value prices of new and continuing goods. The third term is interpreted as showing the substitution effects that occur through product turnover. The final term represents the cross-effect of the substitution effects and price change effects that are supposed to be quite small.

III. Point-of-Sales Data

In our empirical analyses, we use Japanese store-level weekly POS data, known as the SRI,[11] collected by INTAGE Inc. The data set contains information on weekly store-level sales of processed foods, daily necessities, and cosmetics that have commodity codes and

[11] SRI is the abbreviation for the Japanese "Syakaichosa-kenkyujo Retail Index," which means the "Retail Index by The Institute of Social Research."

a Japanese Article Number.[12] The sample period is between January 2006 and February 2016, which enables us to calculate the yearly rate of price changes that occur between January 2007 and February 2016. The data set covers various types of stores, general merchandise stores (GMSs), supermarkets, convenience stores, drug stores, and specialized stores, including liquor shops, located across Japan. The data set contains detailed information on the volume content of products, such as the number of washing loads for which each box of laundry detergent can be used, as well as standard information, including weight (milliliters or grams), the number of items, and the number of meals for food products. **Table 1** provides a detailed description of the data set used to calculate the aggregated UVPI and the COLIs in the next section. The sales records provide pretax price information. Our data set has 84,958 individual products and, on average, more than five million observations per week.[13]

One noteworthy characteristic of the data set is its detailed commodity classification. In the SRI data, commodities that have volume information are classified into more than 1,000 categories, which is about seven times more than the number of classifications adopted by the Japanese official statistics. As Diewert and Von der Lippe (2010) emphasize, when constructing a UVPI, aggregation over heterogeneous goods must be avoided wherever possible. We expect that the highly detailed classification of our data set will help to mitigate the aggregation bias indicated by Diewert and Von der Lippe (2010). When calculating a UVPI, we take the average unit value price for each brand and category, so that brand-level differences in quality are taken into account.[14]

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[12] Fresh foods are excluded from the data set because they lack commodity codes.
[13] This summary table uses the same data that are used to calculate the Feenstra and Broda–Weinstein COLIs.
[14] To avoid the sample selection effect when calculating the rate of change of individual product prices, we limit the store and category space to a range, such that stores and product categories exist in both the current week and the same week of the previous year.

Table 1: Summary of Weekly POS Data

Store Type	Statistics	# of stores	# of catgories	# of makers	# of products	# of obs (thousand)	Sum of sales (mil. yen)
Total	average	3,438	804	14,439	84,958	5,459	11,089
	standard deviation	182	5	395	5,199	540	851
	min	3,114	789	13,590	78,307	4,484	8,643
	max	3,768	813	15,128	95,910	6,671	14,733
General Merchandise Store	average	203	790	10,891	51,606	1,029	2,974
	standard deviation	9	4	286	2,782	121	234
	min	175	778	10,306	47,499	829	2,470
	max	218	803	11,461	57,536	1,262	3,938
Supermarket	average	980	792	12,535	61,584	2,348	4,529
	standard deviation	24	5	317	3,060	166	309
	min	929	779	11,870	57,067	1,976	3,359
	max	1,042	804	13,122	68,048	2,802	5,528
Drugstore	average	992	708	7,219	36,491	998	1,442
	standard deviation	26	14	357	3,064	137	144
	min	837	666	6,502	31,263	693	916
	max	1,044	734	7,794	42,709	1,292	2,314
Convenience Store	average	737	388	2,039	8,440	459	551
	standard deviation	31	17	69	289	22	64
	min	648	359	1,899	7,843	393	391
	max	790	435	2,296	9,527	504	760
Other	average	526	753	7,830	43,853	625	1,593
	standard deviation	152	10	485	5,049	119	281
	min	387	734	7,261	37,828	463	1,089
	max	793	776	8,821	54,573	922	2,982

IV. Empirical Results

Figure 3 shows the results of the UVPIs based on Equation (4) and the official CPI over the same categories.[15] As we limit the number of product categories, the official CPI in **Figure 3** covers about 10% of the expenditure of representative households.[16] In addition, for the purpose of comparison, the figure shows the UVPI calculated from only continuing goods and the Sato–Vartia COLI, both of which are based on the POS data. The four indexes have very similar movements; in particular, the Sato–Vartia COLI and the UVPI (continuing goods) are very similar. However, wide discrepancies between the official CPI and the UVPI occur in 2007–2008 and from the latter half of 2013 to 2016.

[15] The UVPI and Sato–Vartia COLI are constructed using all store types. We calculate these indexes for each store type and then aggregate them using actual sales weights estimated by INTAGE Inc.
[16] In order to compare the UVPI and the official CPI with a broad base, we use an extended number of categories (1,057) in the SRI data rather than the categories shown in **Table 1**.

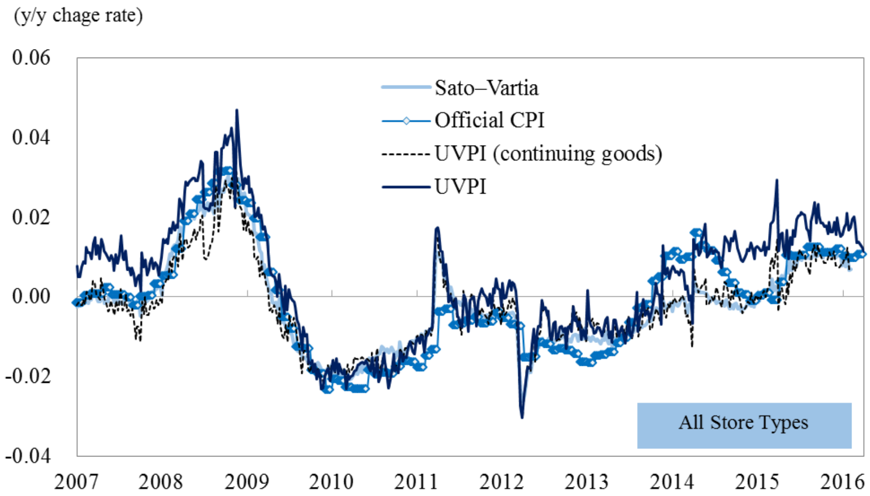

Figure 3: The Unit Value Price Index and the Official Consumer Price Index

Figure 4 shows the UVPI and conventional price indexes: the Laspeyres and Paasche price indexes and the Sato–Vartia COLI, based on the transaction records in supermarket-type stores.[17] Clearly, all indexes have similar up-and-down movements over time, although the UVPI is occasionally slightly higher than the Sato–Vartia COLI. As the standard index theory predicts, the Laspeyres index has a higher inflation rate, whereas the Paasche index has a lower inflation rate than the Sato–Vartia COLI. The average difference between the Laspeyres index and the Paasche index is large, around five percentage points, probably reflecting frequent bargain sales by supermarkets.[18] The Sato–Vartia COLI, which is a composite index of price change rates using weights of the logarithmic average of the base period and the current period sales, has an almost mean value between the Laspeyres index and the Paasche index.

[17] These indexes are calculated from the same categories used by the Feenstra and Broda–Weinstein COLIs for the purpose of comparison.

[18] When bargain sales are implemented in the current period, the prices decline compared with the base period and the quantities sold increase remarkably in the current period. Then, the Paasche index, which is a composite index of price change rates using sales weights for the current period, reflects a price decrease. On the other hand, when bargain sales are implemented in the base period, the prices increase compared with the base period and the quantities decrease. Then, the Laspeyres index, which is a composite index of price change rates using sales weights for the base period, has a strong tendency to show a higher inflation rate with frequent bargain sales.

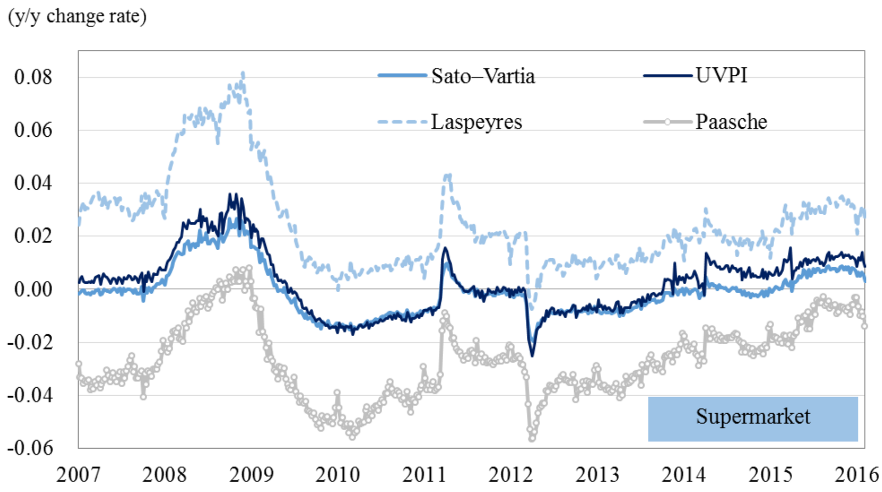

Figure 4: Unit Value Price Index and Traditional Price Indexes

A. Cost of Living Indexes with Product Variety and Unit Value Price Index

As the Laspeyres and Paasche price indexes and the Sato–Vartia COLI are calculated from the set of continuing goods, $g_{t,t-y}$, the product variety effect is not included. To consider the effects of the change in the product space, we need to construct other price indexes, including the Feenstra COLI, the Broda–Weinstein COLI, and the UVPI. We calculate the Feenstra and Broda–Weinstein COLIs based on the POS data using equations (2) and (3), respectively. To calculate these COLIs, we need to estimate the elasticities of substitution for demand based on the POS data. In this study, we adopt the estimation method of Feenstra (1994).[19] The estimation results for the demand and supply elasticities of substitution are summarized in **Table 2**. To avoid measurement errors, we adopt the brands that have estimates for the within-brand elasticity of demand with values that are lower than the 95th percentile. In addition, for the calculation of the COLIs, we adopt the product groups that have estimates for the across-brand elasticity of demand with values that are lower than the 95th percentile.

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[19] The detailed estimation procedure is shown in Appendix B.

Table 2: Estimated Elasticities of Substitution for Demand and Supply

	Within Brand		Across Brand	
	Demand	Supply	Demand	Supply
Percentiles				
0.01	2.842	0.699	1.325	-0.810
0.05	4.336	2.180	2.136	-0.103
0.10	5.344	3.372	2.566	0.470
0.25	7.485	6.238	4.138	2.666
0.50	11.670	11.690	8.769	13.082
0.75	24.596	25.431	32.455	42.874
0.90	74.102	72.531	96.117	104.307
0.95	177.241	167.347	166.129	181.368
0.99	1,749.787	1,928.260	894.507	582.915
Number of Estimates	22,841	22,833	862	862

The results of the Feenstra and Broda–Weinstein COLIs based on the POS data are shown in **Figure 5**. Whereas the Feenstra COLI reflects only the product variety effects in each brand, the Broda–Weinstein COLI reflects both the effects of product variety in each brand and brand variety in each product group. In addition, we show the results of the Sato–Vartia COLI as a basis for comparison in this figure. As the Sato–Vartia COLI is calculated from the set of continuing goods, the differences of the other indexes from the Sato–Vartia COLI reveal the effects of product variety change and brand variety change. We find that the Feenstra COLI and the Broda–Weinstein COLI have lower inflation rates than those calculated by the Sato–Vartia COLI. Thus, the variety change has negative effects on the general inflation rate. However, the difference between the Feenstra and Broda–Weinstein COLIs is very small.

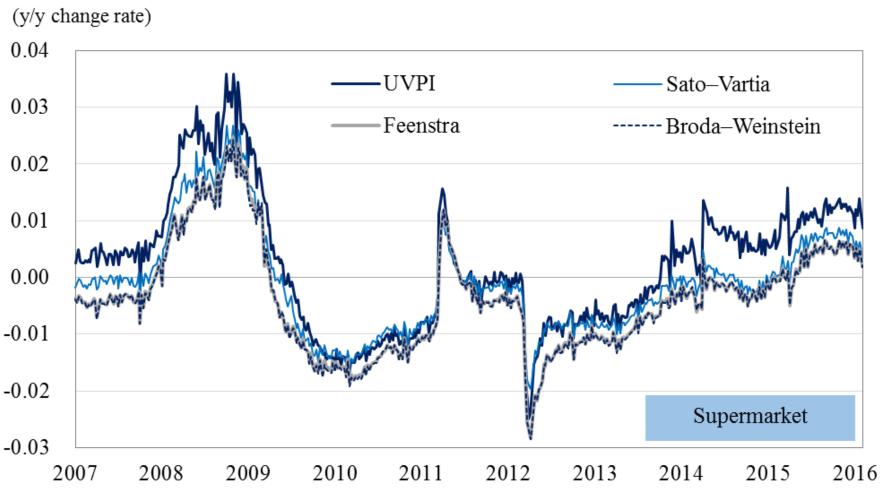

Figure 5: Sato–Vartia, Feenstra, and Broda–Weinstein COLIs and the Unit Value Price Index

Figure 6 shows the aggregated within-brand and across-brand lambda ratios that are adjusted by within-brand and across-brand substitution elasticities, respectively. Whereas the within-brand lambda ratios adjusted by substitution elasticities are significantly lower than unity, the across-brand lambda ratios adjusted by substitution elasticities have very small fluctuations away from unity. Here, we use manufacturer information to identify brands because of the difficulty of identifying within-brand variety in a manufacturer's products. Thus, the effects of brand variety changes are small.[20]

[20] We use only the estimates of within-brand elasticities to calculate Feenstra's COLI in which brands are considered as product groups.

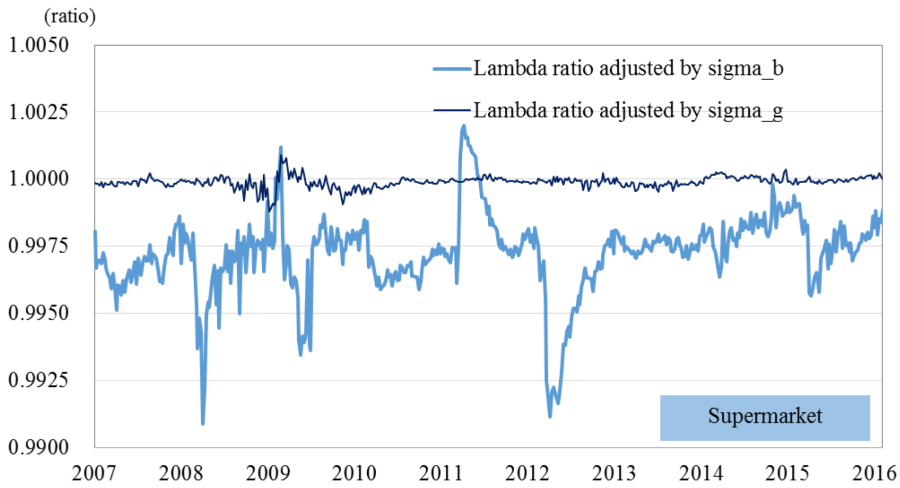

Figure 6: Aggregated Lambda Ratios for Within Brands and Across Brands

As **Figure 5** shows, the UVPI is generally higher than the Sato–Vartia, Feenstra, and Broda–Weinstein COLIs. The remarkable advantage of the UVPI is that, when the total number of products is unchanged, if newly introduced but virtually identical goods are relatively more expensive than the old goods that they replace, the UVPI exhibits higher inflation. In contrast, the Feenstra and Broda–Weinstein COLIs show no inflation. The distance between the UVPI and the other COLIs widens after the increase in the consumption tax rate that occurred in April 2014. During that period, many producers released new products that had virtually identical contents to their old products and were sold at the same prices, but had reduced volumes. The introduction of such "new" goods was observed frequently in Japan during this period.

B. Decomposition of the Unit Value Price Index

Figure 7 shows the results of the decomposition of our UVPI into the three components outlined earlier. We observe positive contributions from the product turnover effect during 2007, 2008, and the period after 2014. We suspect that many producers effectively raised prices through product turnover and volume change in these periods, with limited changes in product quality. The substitution effects are generally negative, implying a negative correlation between the change of volume shares and prices. The substitution effects strengthened just before the tax revision, probably reflecting consumers' stockpiling behavior, which significantly reduced the inflation rate of the UVPI.

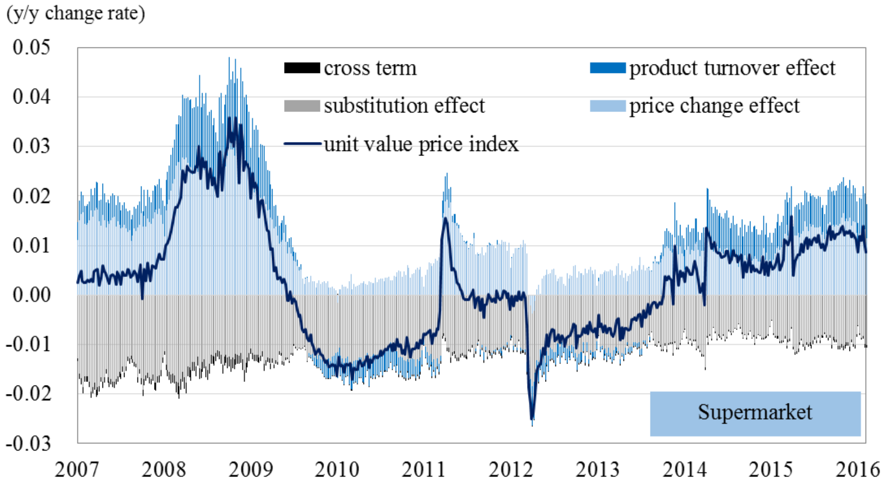

Figure 7: Decomposition of the Unit Value Price Index

C. Unit Value Price Index by Store Type

Figure 8 shows the results of decomposition of the UVPIs by store type. We observe that the decomposition graphs for the GMSs and supermarkets are very similar. In addition, it is clear that the price change and substitution effects for drugstores are smaller than those for supermarkets and GMSs. In the decomposition for convenience stores, the price change effects are small and the substitution effects are almost zero. We suspect that the prices of goods sold in convenience stores are adjusted mainly via product turnover. **Figure 9** compares the UVPI and COLIs with product variety effects in each store type. We find that the distance between the UVPI and COLIs with product variety is largely the result of the product turnover effects for each store type.

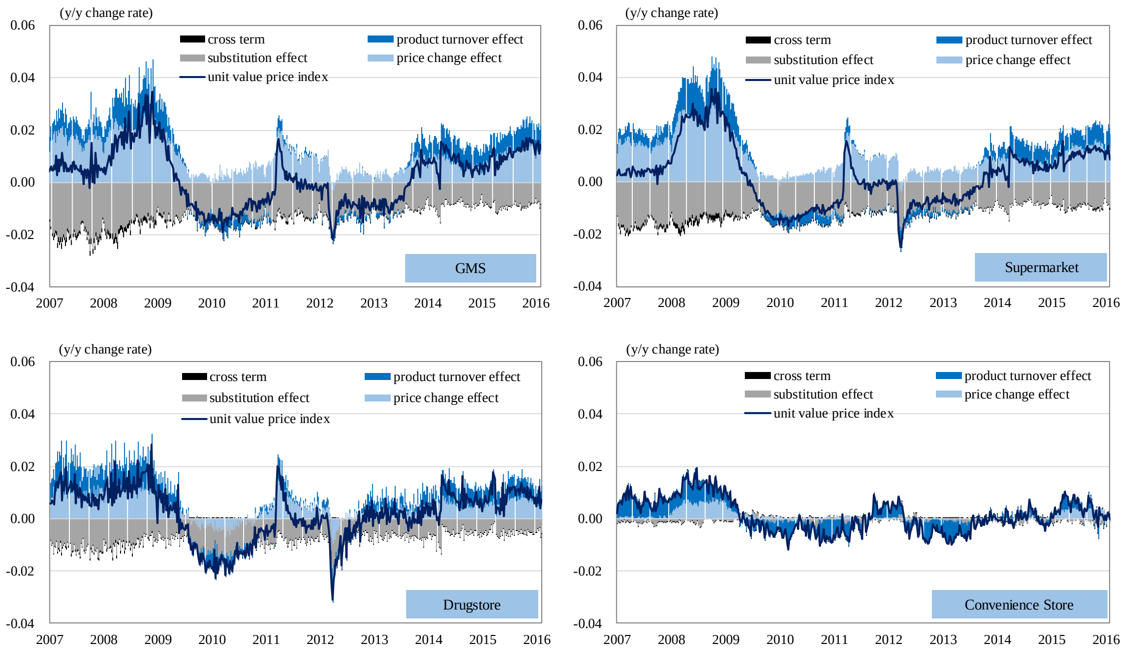

Figure 8: Decomposition of the Unit Value Price Index by Store Type

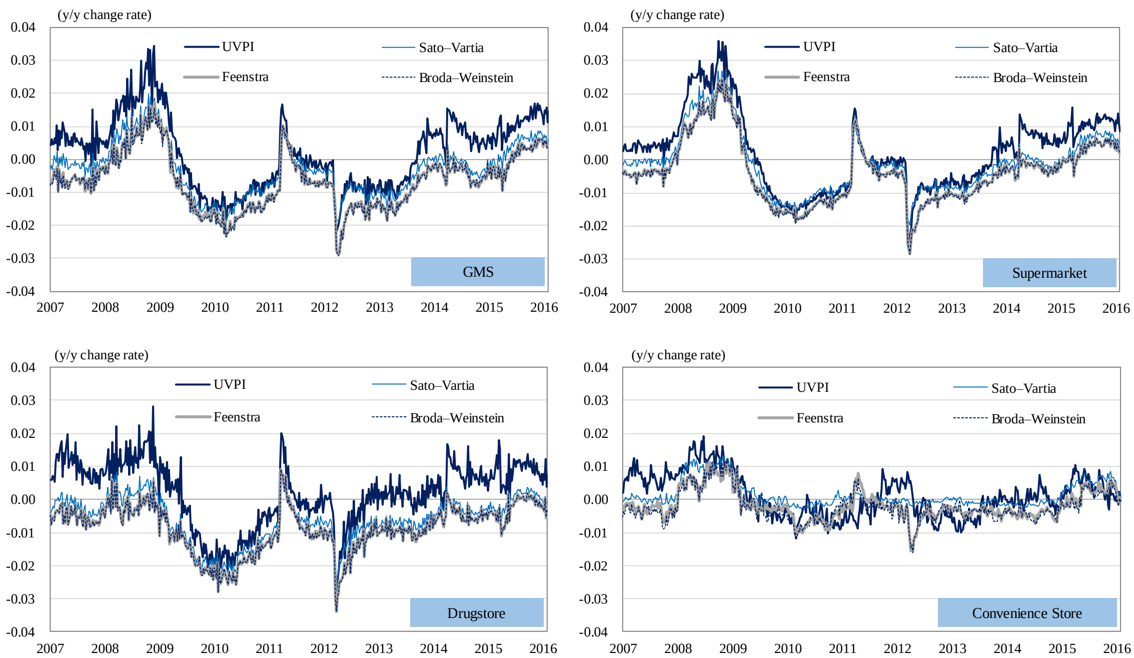

Figure 9: Sato–Vartia, Feenstra, and Broda–Weinstein COLIs and the UVPI by Store Type

VI. Quality Issues

As already pointed out, the turnover/new product effects are composed of two different effects, changes in prices and changes in quality. It is virtually impossible to quantify the contribution of the changes in quality within the turnover/new product effects. However, by examining some cases of product turnover, we can gain some insight into the relative importance of changes in quality.

Between April 2014 and March 2015, the turnover/new product effect in supermarkets is about 1.5 percentage points. About two-thirds of the increase came from changes in the following six product categories: yogurt drinks, Vienna sausage, soft plain yogurt, processed cheese, sake (rice wine), and ice cream. **Figure 10** shows the movements in the average price and sales volume of these product categories, based on the products with the largest market shares for each of these six categories. Three products underwent volume changes when the new products were introduced, without any statement about quality improvements being made in their advertisements. For example, one processed cheese product was reduced from eight slices of cheese to seven slices, with each slice having the same volume and ingredients as the old product. Three commodities claimed improvements in quality; for instance, a new yogurt drink that appeared in September 2013 came in a new container that was supposed to be easier to open, and it was claimed that a new Vienna sausage introduced in early 2014 was tastier. Sake, Japanese rice wine, is different from the other product categories. There was no major sake product that contributed to the commodity-level turnover effects, implying that the increase in the turnover/new product effects came from a number of different commodities with minor market shares.

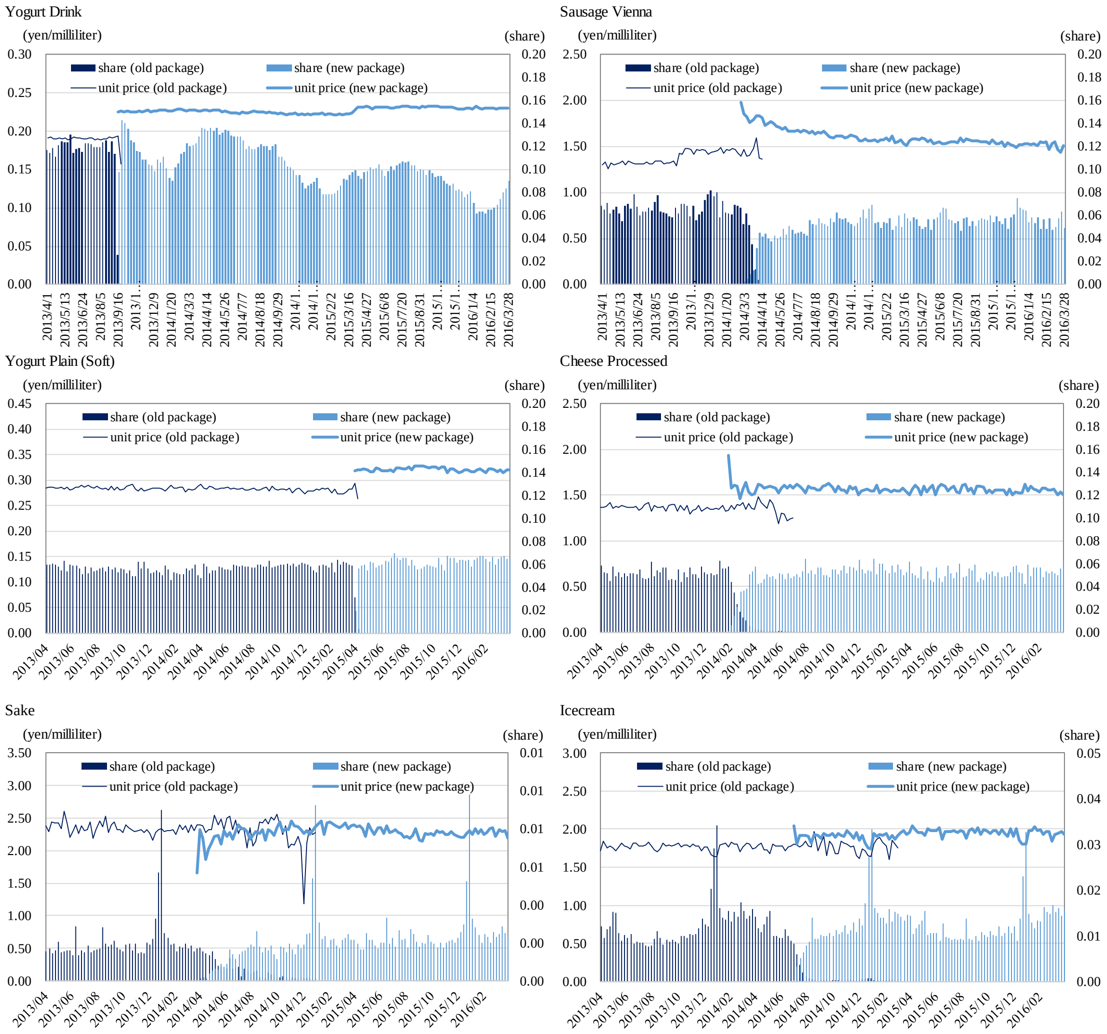

Figure 10: Some Cases of Product Turnovera

Notes: The right axes show the market share of the item within the commodity group and the left axes indicate the unit value price.

VII. Conclusion

This study has investigated UVPIs and COLIs with product variety based on large-scale retail scanner data. The scanner data cover the product categories of processed food, daily necessities, and cosmetics. By extending the technique developed by Silver (2009,

2010) and Diewert and Von der Lippe (2010), we decomposed changes in the UVPI into three contributions: (1) price change effects (Laspeyres price index), (2) substitution effects, and (3) turnover/new goods effects. The aggregate UVPI shows a higher rate of inflation than do COLIs, including the Sato–Vartia, Feenstra, and Broda–Weinstein COLIs. Product turnover effects are generally positive, implying that new products are priced higher than are disappearing or continuing goods. Substitution effects are generally negative, implying a negative correlation between volume shares and prices. Substitution effects strengthened just prior to Japan's consumption tax revision in 2014, probably reflecting consumers' stockpiling behavior, which significantly reduced the inflation rate of the UVPI. After the tax rate increased, the turnover/new product effects increased by one percentage point, contributing to the increase in unit value prices.

Analyses at the store-type level revealed that the influence of the three effects on the UVPI varied greatly across store types. We observed that the contributions of the price change and substitution effects in drugstores are smaller than those in supermarkets and GMSs. The decomposition of the UVPI for convenience stores shows an even smaller price change effect, while the substitution effect is virtually zero.

There are a number of tasks relating to our work that remain a subject for future research. The increasing share of new goods in total sales after Japan's tax revision implies that the introduction of new goods is used as an instrument for price adjustment to a certain extent. The increase in the UVPI after the tax revision was caused largely by the introduction of more highly priced new goods. If factors such as potential damage to product brands prevent producers from changing prices, the introduction of new, slightly different (e.g., reduced volume) goods could be a means of avoiding price increases while reducing costs for producers. Microanalyses of price and product adjustments merit further investigation.

The UVPI did not capture changes in product quality, such as taste or durability. In general, the quality of processed foods and daily necessities is very difficult to measure. The Statistics Bureau of Japan does not adjust for the quality of processed foods and daily necessities, except for volume (changes in grams or milliliters), when constructing its CPI. As there is scarce information about the characteristics of processed food and daily necessities, except for volume, it is difficult to employ a hedonic approach. As Section 6 discusses, we suspect the contribution of changes in quality is minor in our UVPIs. However, more detailed categorical-level investigations are needed to address the quality issue further.

Other tasks remaining for future research include analyses of: (1) the effects of the tax rate on the cycle of products introduced just before the tax reform; (2) other possible measures for the COLI, including the multilateral chained index proposed by De Haan and Van der Grient (2011); and (3) the impact on commodity prices of the large depreciation in the Japanese yen in 2012.[21]

[21] Recent works including Shioji (2015) and Hara et al. (2015) show that the exchange rate pass-through into the Japanese price index increased after 2010.

Appendix A

A.1. Rate of Inflation of the Unit Value Price Index

The inflation rate of the UVPI, $\pi_t^U (\equiv \frac{P_t^U - P_{t-y}^U}{P_{t-y}^U})$, can be written as follows:[22]

$$\pi_t^U = \left(\frac{P_{t-y}^{UC}}{P_{t-y}^U}\right)\frac{w_t^C P_t^{UC} - w_{t-y}^C P_{t-y}^{UC}}{P_{t-y}^{UC}} + \left(\frac{P_{t-y}^{UO}}{P_{t-y}^U}\right)\frac{w_t^N P_t^{UN} - w_{t-y}^O P_{t-y}^{UO}}{P_{t-y}^O}.$$

We rewrite this equation as:

$$\pi_t^U = \left(\frac{P_{t-y}^{UC}}{P_{t-y}^U}\right) w_{t-y}^C \hat{\pi}_t^{UC} + \left(\frac{P_{t-y}^{UO}}{P_{t-y}^U}\right) w_{t-y}^O \hat{\pi}_t^{UT},$$

where $\hat{\pi}_t^{UC} \equiv \frac{(w_t^C / w_{t-y}^C) P_t^{UC} - P_{t-y}^{UC}}{P_{t-y}^{\mathrm{UC}}}$ and $\hat{\pi}_t^{UT} \equiv \frac{(w_t^N / w_{t-y}^O) P_t^{UN} - P_{t-y}^{UO}}{P_{t-y}^{UO}}$.

A.2. Price Change Effects and Substitution Effects

We define the Laspeyres price index of the continuing goods (π_t^{LC}) as follows:[23]

$$\pi_t^{LC} = \frac{\sum_{i \in g_{t,t-y}} \left[\frac{q_{t-y}^i}{\sum_{i \in g_{t,t-y}} q_{t-y}^i} \times p_t^i\right] - \sum_{i \in C_t} \left[\frac{q_{t-y}^i}{\sum_{i \in g_{t,t-y}} q_{t-y}^i} \times p_{t-y}^i\right]}{\sum_{i \in C_t} \left[\frac{q_{t-y}^i}{\sum_{i \in g_{t,t-y}} q_{t-y}^i} \times p_{t-y}^i\right]}$$

$$= \frac{\sum_{i \in g_{t,t-y}} \left[q_{t-y}^i p_t^i\right]}{\sum_{i \in g_{t,t-y}} \left[q_{t-y}^i p_{t-y}^i\right]} - 1.$$

As π_t^{LC} captures the effects of price changes of the continuing goods, we refer to it as the price change effects.

The substitution effect of continuing goods (ϕ_{t}^{UC}) is defined as:

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[22] In the appendix, we omit the indicator of product category g. Thus, here, we denote P_t^U as $P_t^U(g)$.

[23] In the appendix, p_t^i denotes p_t^i / v^i in the main text and q_{t-y}^i denotes $v^i q_{t-y}^i$ in the main text.

$$\phi_{\mathrm{t}}^{UC} \equiv \frac{P_t^{UC} - \ddot{P}_t^{UC}}{P_t^{\mathrm{UC}}},$$

where $\ddot{P}_t^{UC} = \sum_{i \in g_{t,t-y}} \left[\frac{q_{t-y}^i}{\sum_{i \in g_{t,t-y}} q_{t-y}^i} \times p_t^i \right]$.

Diewert and Von der Lippe (2010) define covariance such that:

$$\mathrm{Cov}(x, y) = \frac{1}{T} \sum_i (x_i - x^*)(y_i - y^*) = \frac{1}{T} \sum_i (x_i)(y_i - y^*),$$

where

$$s_t^i = \frac{q_t^i}{\sum_{i \in g_{t,t-y}} q_t^i}, p_{\mathrm{t}} = \left[p_t^1, p_t^2, \dots, p_t^{T_t}\right], \text{and } s_t = \left[s_t^1, s_t^2, \dots, s_t^{T_t}\right],$$

where T_t: $\#(\Theta_t)$ is the number of products sold at time t.

The substitution effects (ϕ_t^C) can be transformed as follows:

$$\phi_t^{UC} \equiv \frac{P_t^{UC} - \ddot{P}_t^{UC}}{P_t^{UC}} = \frac{\sum_{i \in g_{t,t-y}} p_t^i \left[\frac{q_t^i}{\sum_{i \in g_{t,t-y}} q_t^i} - \frac{q_{t-y}^i}{\sum_{i \in g_{t,t-y}} q_{t-y}^i} \right]}{\sum_{i \in C_t} \left[\frac{q_t^i}{\sum_{i \in g_{t,t-y}} q_t^i} \times p_t^i \right]}$$

$$= \frac{\sum_{i \in g_{t,t-y}} p_t^i \left[s_t^i - s_{t-y}^i\right]}{\sum_{i \in g_{t,t-y}} \left[\frac{q_t^i}{\sum_{i \in g_{t,t-y}} q_t^i} \times p_t^i \right]}.$$

Because s_t^i and s_{t-y}^i are the volume shares of good *i* in times *t* and *t*−*y*, respectively, their averages are the same. That is, $\sum_{i \in C_t} \left[s_t^i - s_{t-y}^i\right] = 0$.

Thus, we obtain:

$$\sum_{i \in c_t} p_t^i \left[s_t^i - s_{t-y}^i\right] = T_t \mathrm{Cov}\left(p_t, s_t - s_{t-y}\right).$$

Therefore, the substitution effects can be written by the following covariance:

$$\phi_t^{UC} = \frac{T_t \mathrm{Cov}(p_t, s_t - s_{t-y})}{P_t^{UC}}.$$

The RHS of the above equation is equivalent to the formula derived by Diewert and Von der Lippe (2010). The interpretation of the covariance term is straightforward. If the price of good *i* were to exceed the average price, its volume share would be expected to decline. This substitution effect captures the degree of the negative correlation.

A.3. Decomposition of $\hat{\pi}_t^C$

To interpret the term with $\hat{\pi}_t^C$, we introduce variable $\tilde{\pi}_t^C$, as follows:

$$\tilde{\pi}_t^{UC} \equiv \hat{\pi}_t^{UC} - \pi_t^{LC}$$

$$= \left(w_t^C / w_{t-y}^C - 1\right) \frac{P_t^{UC}}{P_{t-y}^{UC}} + \frac{P_t^{UC} - \ddot{P}_t^{UC}}{P_t^{UC}} \frac{P_t^{UC}}{P_{t-y}^{UC}}$$

$$= \left(w_t^C / w_{t-y}^C - 1\right)(1 + \pi_t^{UC}) + \phi_t^C (1 + \pi_t^{UC}),$$

where $\pi_t^{UC} \equiv \frac{P_t^{UC} - P_{t-y}^{UC}}{P_{t-y}^{UC}}$.

Therefore, $\hat{\pi}_t^{UC}$ can be expressed as:

$$\hat{\pi}_t^{UC} = \pi_t^{LC} + \phi_t^{UC} + \left(w_t^C / w_{t-y}^C - 1\right) + \left[\left(w_t^C / w_{t-y}^C - 1\right)\pi_t^{UC} + \phi_t^{UC} \pi_t^{UC}\right].$$

$\hat{\pi}_t^{UC}$ can be decomposed into four effects: (1) the price change effects of continuing goods, π_t^{LC}; (2) the substitution effects within continuing goods, ϕ_t^{UC}; (3) the changes in the weights of continuing goods between periods *t* and *t*−y, $\left(w_t^C / w_{t-y}^C - 1\right)$; and (4) the cross-terms.

A.4. Decomposition of $\hat{\pi}_t^{UT}$

$\hat{\pi}_t^{UT}$ can be decomposed into three effects: (1) the changes in the weights of new and disappearing goods, $\left(w_t^N / w_{t-y}^O - 1\right)$; (2) the price differential between new and disappearing goods, π_t^{NO}; and (3) the cross-term, as follows:

$$\hat{\pi}_t^{UT} = \left(w_t^N / w_{t-y}^O - 1\right) + \pi_t^{NO} + \left(w_t^N / w_{t-y}^O - 1\right)\pi_t^{NO},$$

where $\pi_t^{NO} \equiv \frac{P_t^{UN} - P_{t-y}^{UO}}{P_{t-y}^{UO}}$.

A.5. Unit Value Price Decomposition

π_t^U can be expressed as:

$$\begin{aligned}\pi_t^U = &\left(\frac{P_{t-y}^{UC}}{P_{t-y}^U}\right) w_{t-y}^C \pi_t^{LC} + \left(\frac{P_{t-y}^{UC}}{P_{t-y}^U}\right) w_{t-y}^C \phi_t^{UC} + \left(\frac{P_{t-y}^{UO}}{P_{t-y}^U}\right) w_{t-y}^O \pi_t^{NO} \\ &+ \left(\frac{P_{t-y}^{C}}{P_{t-y}^{\Theta}}\right)\left(w_t^C - w_{t-y}^C\right)\pi_t^{UC} + \left(\frac{P_{t-y}^{UO}}{P_{t-y}^U}\right)\left(w_t^N - w_{t-y}^O\right)\pi_t^{NO} \\ &+ \left(\frac{P_{t-y}^{UO} - P_{t-y}^{UC}}{P_{t-y}^U}\right)\left(w_t^N - w_{t-y}^O\right) + \left(\frac{P_{t-y}^{UC}}{P_{t-y}^U}\right) w_{t-y}^C \phi_t^{UC} \pi_t^{UC}.\end{aligned}$$

The third, fourth, fifth, and sixth terms on the RHS of the above equation can be simplified significantly, as follows:

$$\begin{aligned}&\left(\frac{P_{t-y}^{UO}}{P_{t-y}^U}\right) w_{t-y}^O \pi_t^{NO} + \left(\frac{P_{t-y}^{C}}{P_{t-y}^{\Theta}}\right)\left(w_t^C - w_{t-y}^C\right)\pi_t^{UC} + \left(\frac{P_{t-y}^{UO}}{P_{t-y}^U}\right)\left(w_t^N - w_{t-y}^O\right)\pi_t^{NO} \\ &+ \left(\frac{P_{t-y}^{UO} - P_{t-y}^{UC}}{P_{t-y}^U}\right)\left(w_t^N - w_{t-y}^O\right) \\ &= \frac{w_{t-y}^O\left(P_t^{UC} - P_{t-y}^{UO}\right) + w_t^N (P_t^{UN} - P_t^{UC})}{P_{t-y}^U}.\end{aligned}$$

Note that $w_t^C - w_{t-y}^C = 1 - w_t^N - \left(1 - w_{t-y}^O\right) = -(w_t^N - w_{t-y}^O)$.

Thus, we obtain:

$$\begin{aligned}\pi_t^U = &\left(\frac{P_{t-y}^{UC}}{P_{t-y}^U}\right) w_{t-y}^C \pi_t^{LC} + \left(\frac{P_{t-y}^{UC}}{P_{t-y}^U}\right) w_{t-y}^C \phi_t^{UC} + \frac{w_{t-y}^O\left(P_t^{UC} - P_{t-y}^{UO}\right) + w_t^N (P_t^{UN} - P_t^{UC})}{P_{t-y}^U} \\ &+ \left(\frac{P_{t-y}^{UC}}{P_{t-y}^U}\right) w_{t-y}^C \phi_t^{UC} \pi_t^{UC}.\end{aligned}$$

Appendix B

Feenstra (1994) estimates the substitution elasticity for demand and supply simultaneously based on continuing goods transaction data. In Subsection 2.1, we assume composite consumption, as follows:

$$C_t^g = \left(\sum_{i \in g_t} \alpha_i \left(q_t^i \right)^{\frac{\sigma_g - 1}{\sigma_g}} \right)^{\frac{\sigma_g}{\sigma_g - 1}}.$$

Then, the consumption share of product i in category g is given by the following expression:

$$w_t^i = \left(\frac{E_t}{C_t^g} \right)^{\sigma_g - 1} a_i^{\sigma_g} {p_t^i}^{1-\sigma_g},$$

where $w_t^i = p_t^i q_t^i / (\sum_{i \in g_{t,t-y}} p_t^i q_t^i)$.

Taking the log in the first difference of this expression yields:

$$\Delta \ln w_t^i = \gamma_t - (\sigma_g - 1) \Delta \ln p_t^i + \varepsilon_t^i,$$

where γ_t=$(\sigma_g - 1)\Delta\ln(E_t / C_t^g)$ and $\varepsilon_t^i = \sigma_g \ln a_i$.

The supply curve of product i in category g is specified in the following log difference form:

$$\Delta \ln p_t^i = \omega_g \Delta \ln q_t^i + \xi_t^i,$$

where ω_g is the inverse supply elasticity and ξ_t^i is a supply shock, which is assumed independent to ε_t^i. From equations (A1) and (A2), we obtain the following expression:

$$\Delta \ln p_t^i = \psi_t + \frac{\rho}{\sigma_g - 1} \varepsilon_t^i + \delta_t^i,$$

where $\psi_t = \frac{\omega_g}{1+\sigma_g \omega_g} (\gamma_t + \Delta \ln E_t)$, $\delta_t^i = \xi_t^i / (1 + \sigma_g \omega_g)$, and $\rho = \omega_g (\sigma_g - 1)/(1 + \sigma_g \omega_g)$.

If we were to subtract the same functions for product k in category g from equations (A1) and (A3), we could eliminate γ_t and ψ_t and obtain the following expression:

$$\tilde{\varepsilon}_t^i = \left(\Delta \ln w_t^i - \Delta \ln w_t^k\right) + (\sigma_g - 1)\left(\Delta \ln p_t^i - \Delta \ln p_t^k\right)$$

$$\tilde{\delta}_t^i = (1-\rho)\left(\Delta \ln p_t^i - \Delta \ln p_t^k\right) - \left(\frac{\rho}{\sigma_g - 1}\right)\left(\Delta \ln w_t^i - \Delta \ln w_t^k\right),$$

where $\tilde{\varepsilon}_t^i = \varepsilon_t^i - \varepsilon_t^k$ and $\tilde{\delta}_t^i = \delta_t^i - \delta_t^k$. Multiplying these two equations and dividing the result by $(1-\rho)(\sigma_g - 1)$, we obtain the following equation:

$$Y_t^i = \theta_1 X_t^i + \theta_2 Z_t^i + u_t^i,$$

where

$$Y_t^i = \left(\Delta \ln p_t^i - \Delta \ln p_t^k\right)^2, X_t^i = \left(\Delta \ln w_t^i - \Delta \ln w_t^k\right)^2,$$

$$Z_t^i = \left(\Delta \ln w_t^i - \Delta \ln w_t^k\right)\left(\Delta \ln p_t^i - \Delta \ln p_t^k\right),$$

$$u_t^i = \frac{\tilde{\varepsilon}_t^i \tilde{\delta}_t^i}{(1-\rho)(\sigma_g - 1)}, \theta_1 = \frac{\rho}{(1-\rho)\left(\sigma_g - 1\right)^2}, \theta_2 = \frac{(2\rho - 1)}{(1-\rho)\left(\sigma_g - 1\right)}.$$

To obtain consistent estimators, we take the average of equation (A4) for all t:

$$\bar{Y}^i = \theta_1 \bar{X}^i + \theta_2 \bar{Z}^i + \bar{u}^i.$$

From the assumption of demand and supply shocks, $\mathrm{E}\left(\bar{u}^i\right) = 0$. We estimate σ_g and ω_g using equation (A5) by GMM.

When we perform the within-brand estimation, we denote the individual price and share in the brand as p_t^i and w_t^i, respectively. When we estimate the within-brand estimation, we adopt $PI_{SV}\left(p_t, p_{t-y}, b_{t,t-y}\right)\left(\frac{\lambda_{bt}^{\mathrm{cr}}}{\lambda_{bt}^{\mathrm{bs}}}\right)^{\frac{1}{\sigma_b - 1}}$ and

$w_t^b = \frac{\sum_{i \in b_{t,t-y}} p_t^i q_t^i}{\sum_{b \in g} \sum_{i \in b_{t,t-y}} p_t^i q_t^i}$ as p_t^i and w_t^i, respectively, in this estimation procedure.

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