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Product Turnover and Deflation: Evidence from Japan

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Abstract

In this study, we evaluate the effects of product turnover on a welfare-based cost-of-living index. We first present several facts about price and quantity changes over the product cycle employing scanner data for Japan for the years 1988-2013, which cover the deflationary period that started in the mid 1990s. We then develop a new method to decompose price changes at the time of product turnover into those due to the quality effect and those due to the fashion effect (i.e., the higher demand for products that are new). Our main findings are as follows: (i) the price and quantity of a new product tend to be higher than those of its predecessor at its exit from the market, implying that Japanese firms use new products as an opportunity to take back the price decline that occurred during the life of its predecessor under deflation; (ii) a considerable fashion effect exists, while the quality effect is slightly declining; and (iii) the discrepancy between the cost-of-living index estimated based on our methodology and the price index constructed only from a matched sample is not large. Our study provides a plausible story to explain why Japan's deflation during the lost decades was mild.

Keywords: cost-of-living index; product creation and destruction;
fashion effect; substitution; lost decades

JEL classification: C43, E31, E32, O31

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1 Introduction

Central banks need to have a reliable measure of inflation when making decisions on monetary policy. Often, it is the consumer price index (CPI) they refer to when pursuing an inflation targeting policy. However, if the CPI entails severe measurement bias, monetary policy aiming to stabilize the CPI inflation rate may well bring about detrimental effects on the economy. One obstacle lies in frequent product turnover; for example, supermarkets in Japan sell hundreds of thousands of products, with new products continuously being created and old ones being discontinued. The CPI does not collect the prices of all these products. Moreover, new products do not necessarily have the same characteristics as their predecessors, so that their prices may not be comparable.

In this paper, we aim to evaluate the effects of product turnover on a price index by employing daily scanner, or point of sale (POS), data for Japan. To illustrate the importance of product turnover, let us look at price changes in shampoos. The thick line in Figure 1 shows the price of shampoos drawn from a *matched sample*, computed in a similar way to the CPI.[1] Here, a matched sample denotes a set of products that exist in two months and whose prices thus can be compared. The thick line shows a clear secular decline in the price of shampoo. On the other hand, the thin line depicts the unit price of shampoos. The unit price corresponds to the total sales of shampoos divided by the total quantity of shampoos sold in all stores in a certain month, indicating how much a representative household spends on purchasing one unit of shampoo. The graph reveals that the unit price of shampoo rose in the early 1990s and has remained almost constant since the mid-1990s. We therefore observe no deflation. Finally, the price of shampoos reported in the CPI, represented by the dashed line in the graph, moves between the two lines.

Why does this difference arise? Figure 2 illustrates the reason. In Japan, product prices tend to decline over time from the price level at market entry (birth) $p(t'_b)$, and the price of a new product at entry (birth) $p(t_b)$ is generally higher than that of its predecessor at exit (death) $p(t'_d)$. In other words, firms recover the price decline in their products by introducing new products. The unit price incorporates both new and old products and

[1]The CPI is compiled by calculating the ratio of the price of each product in a month to that in the previous month for a *comparable* product. To compare prices, therefore, the product needs to exist in two consecutive months. If a product is discontinued and replaced by a new noncomparable product, a quality adjustment is made. See, for example, Greenlees and McClelland (2011).

hence increases when a high-priced new product appears and a low-priced old product disappears. In contrast, the average price of the matched sample is depicted by the red dashed line in the figure. Because we compare the prices of identical products only, it continues to decline even if high-priced new products appear. This treatment would be valid if the quality difference between old and new products happens to coincide with the price difference between the two (i.e., the difference between the price of a product when it exits from the market and the price of its successor when it enters the market). On the other hand, if there is no quality change at the timing of product turnover, the unit price provides a precise cost-of-living index. Because the line of the CPI lies between other two lines in Figure 1, Japan's statistics office seems to assume that quality changes explain almost half of the price increase when new products are introduced.

In addition to the measurement of the price index, our study aims to shed new light on Japan's deflation from the perspective of product turnover. Japan is unique in that the Japanese economy experienced prolonged deflation from the mid-1990s onwards. On average, the CPI fell by 0.3% annually from 1999 to 2012. In this study, we address at what level prices are set when products are created compared to disappearing products, how their prices develop before they are discontinued, and how these price patterns changed during the lost decades. Moreover, we consider why deflation has been mild and Japan avoided a deflationary spiral.

To this end, we employ Japanese scanner data from March 1988 to October 2013 and document the pattern of price changes over the product cycle. We then construct a welfare-based price index, or cost-of-living index (COLI), that incorporates product turnover taking the quality and fashion effects into account. A successor product may be better in terms of its quality than its predecessor; or consumers may derive utility simply from buying a new product, as highlighted by Bils (2009).[2] Both aspects naturally lead to an increase in welfare and thus result in a decrease in the COLI. Even though the unit price increases when new products enter the market, both the quality and fashion effects contribute to lowering the COLI rather than raising it.

It is thus particularly important to separate the quality and fashion effects from the

[2]Bils (2009) provides the following example of the fashion effect: "Persons may prefer to consume a novel shortly after its arrival on the market, perhaps because they wish to discuss the book with others currently reading it, ... but we would not want to infer from this that novels are getting better and better."

price effect in calculating the COLI when an old product is replaced by a new one. In that regard, we borrow from Feenstra (1994) and Bils (2009). Feenstra (1994) proposes a method to incorporate the quality effect in calculating the COLI. Underlying this is the idea that if a new product has a higher sales share than its predecessor, this implies quality improvement. Thus, by comparing the sales share of both new and old products, we can quantify the rate of change in the COLI. However, his method does not incorporate the fashion effect pointed out by Bils (2009). Even if a new product has a higher share, this may reflect the fashion effect, which is transitory, rather than a quality improvement. We therefore extend Feenstra's model to incorporate the fashion effect by assuming that consumers gain utility simply from purchasing a newly created product, even if its quality is the same as that of the product it replaces, and that this effect lasts for a finite period. We then provide a formula to compute the COLI that incorporates both the quality and fashion effects and apply this to Japan.

We present five major stylized facts from the data and two results from the model-based analysis. The five stylized facts are as follows. First, the rate of product turnover is about 30% annually. This rate is higher than that in the United States. Second, the fraction of products whose price declined over their life span increased as deflation became more ingrained, but even in the period of inflation before then many products experienced a price decline over their life span. In 1990, about 20% of products whose lives ended did so with a price decline. This share steadily increased to 30% in 2010. Third, the speed of price decline over the life of a product is higher the shorter the life span of the product. This creates heterogeneous inflation developments across the life span of products, where shorter-life products experience greater deflation. Fourth, successors tend to recover prices. The price of a new product at entry is about 10% higher than the exit price of the old product it replaced. However, the pattern in periods of inflation and deflation is asymmetric: under inflation, the price of a new product exceeds that of its predecessor at entry, but the prices are almost identical under deflation. Fifth, demand increases at entry are transitory and decay to half in a month, providing evidence of the fashion effect.

Meanwhile, the model-based analysis shows the following. First, we find a considerable fashion effect, while the quality effect is slightly declining during the lost decades. Second, the discrepancy between the COLI estimated based on our methodology and the price index constructed only from a matched sample is not large, although the COLI estimated based on Feenstra's (1994) methodology is significantly lower than the price index constructed only from a matched sample.

Our study provides a plausible story to explain why Japan's deflation during the lost decades was mild. In a stagnant economy, firms frequently created and destroyed their products with the aim to recover the price decline of existing products. They avoided setting the prices of new products at entry below those of the predecessor products. To justify this pricing, firms improved the quality of their products and also exploited the fashion effect simply by introducing new products.

There is a vast literature on the measurement of price indexes – be they consumer price or cost-of-living indexes – in the presence of product turnover with changes in quality. A seminal study is the Boskin Commission Report (1996), which estimates that the upward bias in inflation measured using the CPI is as large as 1%. While this study examines numerous reasons for the bias, Feenstra (1994) concentrates on the effects of product turnover and quality change on the price index, providing an analytical framework to calculate the COLI. His framework has its theoretical basis in the studies by Sato (1976) and Diewert (1976). Also see Melser (2006). Broda and Weinstein (2010) apply Feenstra's method to a wider variety of products to compare the COLI with the CPI. They argue that product turnover means that the "true" inflation rate measured using the COLI is 0.8 percentage points lower than that measured by the CPI. Greenlees and McClelland (2011) employ hedonic regression to construct a quality-adjusted CPI. As for Japan, Imai and Watanabe (2014) examine product downsizing as an example of quality retrogression and report that one third of product turnover during the decade preceding their study was accompanied by a size/weight reduction. Abe et al. (2015) decompose the effects of product turnover on the price index, but not the COLI.

Bils (2009) examines the measurement of price indexes in the presence of product turnover taking the fashion effect as well as the quality effect into account. He decomposes price changes at entry into the quality effect, the fashion effect, and a residual component and concludes that the quality effect accounts for two-thirds of the price increase when a new product replaces an old one. While his analysis does not consider welfare and he hence does not construct a COLI, we borrow his idea and calculate the COLI taking welfare into account. Meanwhile, Redding and Weinstein (2016) propose a unified approach to calculating the COLI under time-varying demand. The aim is to encompass not only the permanent and time-invariant quality effect but also the transitory and time-varying fashion effect. We argue that their model is complementary to ours in that their aim is very similar but uses different assumptions on household utility.

Studies using large-scale datasets of prices include Bils and Klenow (2004), Klenow and Kryvtsov (2008), Nakamura and Steinsson (2008), Klenow and Malin (2011), Melser and Syed (2015) among others. As for Japan, there are studies by Higo and Saita (2007), Abe and Tonogi (2010), and Sudo, Ueda, and Watanabe (2014). The last two studies use the same dataset as our study. The focus of these studies is mainly on price stickiness and appropriate pricing models.

The structure of this paper is as follows. Section 2 explains the scanner data. Section 3 provides stylized facts on product turnover and price changes. Section 4 develops a model to compute the COLI and estimate quality change and fashion effects. Section 5 applies the model to Japan, while Section 6 concludes.

2 Data

This section provides an outline of the data we use, which is the POS scanner data collected by Nikkei Digital Media. The data record the number of units sold and the amount of sales (price times the number of units sold) for each product i and retail shop s on a daily basis t. The observation period runs from March 1, 1988 to October 31, 2013. However, data for November and December 2003 are missing, obscuring product turnover around that period. While the number of retailers increases during our observation period and reaches 300 at the end of the observation period, we limit our observations to 14 retailers that exist throughout the observation period to isolate the true effects of product turnover by excluding the effects of the increase in retailers. Products recorded include processed food and domestic articles. We have observations for 860,000 products in total, with an average of 100,000 products per year and 30,000 products per retailer per year.

The scanner data have two advantages over the CPI and one disadvantage. First, they contain information on quantities as well as prices, enabling us to use the Feenstra's (1994) method to calculate quality changes based on changes in sales shares. Second, the scanner data record all the products that are continuously created and destroyed as long as they are sold by the retailers in the dataset. In the CPI, only representative products are surveyed for each product category, and they are substituted only infrequently. One disadvantage of the scanner data is that their coverage of products is smaller than that in the CPI. Unlike the CPI, the scanner data exclude fresh food, recreational durable goods (such as TVs and PCs), and services (such as rent and utilities). Concretely, our scanner data cover 170 of the 588 items in the CPI. Based on data from the *Family Income and Expenditure Survey*, these 170 items make up 17% of households' expenditure. This narrow coverage somewhat limits the conclusions that can be drawn from our study, but the results nevertheless provide a clue regarding the extent of bias caused by product turnover.

Each product is identified by the Japanese Article Number (JAN) code indicating a product and its producer, together with its product name.[3] To see how the JAN code works, we look at margarine made by Meiji Dairies Corporation and its JAN code in Table 1. The first seven digits of the JAN code, 4902705, are the company code, while the last six digits vary product by product for the same margarine made by the same company. In the first two rows, the product names and quantities are exactly the same, while in the other rows the names differ, indicating different ingredients, packaging, and weights.

This example illustrates the difficulties in linking a successor product to a predecessor even for similar products made by the same company. Moreover, from a household perspective, shoppers do not necessarily choose products from the same company when old products disappear. Thus, in constructing the COLI, which should, by its nature, take the perspective of households, we choose the following two-step strategy to identify product generations. In the first step, we classify products into groups using the 3-digit codes provided by Nikkei Digital Media. There are 214 groups in total. Examples include yogurt, beer, tobacco, and toothbrushes. Importantly, the groups comprise products made by different manufacturers as long as the products fall into the same product group. The second step investigates time-series developments in the products in each group. If product A in a particular group disappears in one month and a new product B in the same group appears in the following month, then we regard A as the predecessor of B. Because there exist as many as 100,000 products each year and the 3-digit product groups

[3]The Distribution Systems Research Institute sets guidelines for the JAN coding, which ask firms to use different JAN codes for products that differ in terms of their labeling, size, color, taste, ingredient, flavor, sales unit, etc. It also encourages firms not to use the same JAN code for at least four years after old products cease to ship.

are not very detailed, we are able to find a successor for most discontinued products. In Appendix A, we explain the method of identification of product cycles in more detail. What is worth noting here is that we identify the timing of entry and exit of a product from the earliest and latest date of its sale, respectively, after aggregating its sales over shops. Also, results around 1988 and 2013 are subject to a censoring problem in that we cannot know the products that entered before March 1988 or exited after October 2013.

Figure 3 provides another illustration of the use of the JAN code. In the graph, we count the number of products each year that have different JAN codes and are named "Kit Kat." "Kit Kat" is a chocolate-covered wafer biscuit bar produced by Nestlé. In Japan, Nestlé sells a great number of "Kit Kat" products in different flavors such as Japanese tea (*maccha*), strawberry cake, bean jam, almond jelly, relaxing cacao, and so on. In 2008, there were more than 60 "Kit Kat" products. This example illustrates the Japanese love for new products, which we think is responsible for the frequent product turnover and the considerable fashion effect in Japan, as we will discuss below.

3 Stylized Facts on Product Turnover and Price Changes

This section presents stylized facts on product turnover and price changes.

3.1 Product Turnover

Stylized Fact 1:

The product turnover rate is 30% annually, which is higher than that in the United States. The turnover rate is also less cyclical than that in the United States.

We first examine the degree of product creation and destruction and developments over time. The top panel of Figure 4 shows developments in the number of products over time. To construct the figure, we counted the number of products at each retailer, normalized the value in 1988 to one, and took the unweighted average over retailers. The graph indicates that the number of products roughly tripled. Notably, the number of products picked up from 1994, shortly after the collapse of the asset market bubble and the beginning of Japan's deflationary lost decades.

Table 2 and the bottom panel of Figure 4 show the basic statistics for and developments over time in the annual rate of product entry and exit. The entry rate for each year is defined as the number of newly born products in the year divided by the total number of products in the previous year. The exit rate is defined as the number of exiting products in the previous year divided by the total number of products in the previous year. The standard deviations of the entry and exit rates reported in the table are calculated by aggregating the entry and exit rates for each 3-digit code product across retailers and then across years and then computing the standard deviations across 3-digit code products. We apply the same method for calculating the minimum and maximum. The annual birth and exit rates generally fluctuate in a range between $30 - 40\%$, implying that products are replaced every three years on average. In most years, the entry rate exceeds the exit rate, leading to the increase in the total number of products shown in the top panel. The entry rate jumped in 1994 and displays no discernible trend thereafter, fluctuating around a value of 40%, while the exit rate gradually increased from 25 to 35%.

Comparing our results with those obtained by Broda and Weinstein (2010), who calculate the rate of product turnover at the product level for the United States and find that the rates of product entry and exit are both 25%, suggests that product cycles in Japan are shorter than those in the United States. Further, investigating the relationship between product turnover rates and business cycles, Broda and Weinstein (2010) find that while the exit rate is constant, the entry rate is more volatile and procyclical. On the other hand, our data for Japan suggest that the entry rate is more volatile than the exit rate, but neither shows cyclicality. During the expansionary period from 2002 to 2007, for example, we observe no clear difference between fluctuations in the entry rate and the exit rate, although the entry rate appears to be slightly more procyclical than the exit rate during the inflationary periods around 1990 and 2008 in that the former has increased relatively more than the latter.

3.2 Price Changes Associated with Product Turnover

Next, we investigate how prices change over a product's life.

Stylized Fact 2:

The fraction of products whose price declined over their life span increased as deflation became more ingrained.

We compare the prices of each product between two points in time: when it enters and when it exits the market. Figure 5 shows developments during our observation period in the fractions of products that experienced a price increase ($dp > 0$ in the graph), a price decrease ($dp < 0$), or no price change ($dp = 0$). The horizontal axis represents the year in which products exited. For example, the values for 2000 are for products that were destroyed in 2000 and created before (or in) 2000.

The figure shows that even in the period of inflation in the early 1990s, many products experienced a price decline over their life span. The early 1990s were a period when the overall CPI inflation rate was still relatively high at around 3%. In this period, the fraction of products experiencing a price decline or increase was very similar at around 20%.

However, from around the early 1990s, the fraction of products that experienced a price decline started to increase, while that of products that experienced an increase started to decline, so that the former began to exceed the latter. While the latter settled down at about 15% from 1995 onward, the fraction of products whose price declined continued to rise until the 2000s and since then has been in the range of 30%. Developments in the latter fraction closely mirror developments in the aggregate CPI: CPI inflation fell below 1% in 1994 and turned negative in 2000. Meanwhile, the fraction of products whose price at exit was unchanged from the price at entry gradually declined from about 70% to 50% over the roughly two decades.

Next, we look at the size of price changes over products' lives. Figure 6 shows the probability density function (PDF) of price changes over products' lives. The horizontal axis represents the size of the price change from entry to exit in logarithm. A positive value indicates that a product experienced a price increase over its life span and vice versa.

The left-hand panel shows a sharp peak at zero, indicating that for a large number products the price at exit is the same as it was at entry. Of course, this does not necessarily mean that the prices of such products remained unchanged throughout their lives. However, it is unlikely that the prices of all these products experience a large number of revisions and then happen to revert to their original level. From this perspective, the observed pattern implies strong price stickiness. In fact, this result is in line with Nakamura and Steinsson's (2011) finding that 40% of products do not experience a single price change during their life span.

Taking a closer look, we further find that the PDF is asymmetric. To magnify the shape of distribution except for its peak at zero, in the right-hand panel of the figure the vertical axis is shown in logarithmic scale. The left tail of the PDF is much thicker than the right tail, suggesting that many products end their lives at a lower price. The second highest mode is observed at $\log(0.5) = -0.69$, indicating that over their life span the price of many products falls to half of their initial price, which partly reflects stock clearance sales.[4]

Stylized Fact 3:
The size of price changes over products' lives is independent of their life span. The speed of price decline over products' lives is higher the shorter their life span.

To examine whether products' life span affects their price, we calculate the correlation between a product's life span and the following two variables that are associated with the price change over a product's life. The first variable is the price change over the product's life, while the second variable is the first variable divided by a product's life span, which indicates the monthly speed of price change over the product's life.

Figure 7 presents developments in the correlation over time. Specifically, the line with circles shows the correlation between the life span and the price change over the product's life, while the line with triangles shows the correlation between the life span and the monthly speed of price change over the product's life. The horizontal axis represents the year when a product exited the market.

In the graph, the line with circles is not significantly different from zero, suggesting that how much the price of a product changes over its life is independent of its life span. By contrast, the line with triangles is significantly negative, that is, the speed of price change over a product's life is negatively correlated with its life span. This suggests that

[4] We also find that the size of price declines increased as deflation became more entrenched, as indicated by the fact that for 2005 the left tail is thicker than for 1995. Thus, taken together the results indicate that more products experienced a price decline and that the size of the price decline over products' life span increased.

products with a shorter life span tend to experience a faster price decline over their life.

This creates heterogeneous inflation developments across products with different life spans. To illustrate this, Figure 8 plots developments in price changes for products categorized in terms of their life span. We find that the shortest-lived products with a life span of 16 to 31 months experience the highest speed of price decline. What is more, the speed of price decline of such products accelerated during the 1990s, exceeding 5% from the second half of the decade onward. On the other hand, the speed of price decline of longer-lived products has been milder and more stable. As a result, the difference in the speed of price decline between short- and long-lived products increased under deflation. Together with the steady increase in the exit rate shown in Figure 4, this result suggests that deflation at the aggregate level may have accelerated due to the increase in short-lived products in the late 1990s and early 2000s.

Stylized Fact 4:
The price of a new product at entry exceeds that of its predecessor at exit. Moreover, under inflation, the price of a new product at entry exceeds that of its predecessor at entry, but under deflation, the two prices are almost equal.

So far, we have investigated price patterns over the life of one specific product. We now turn our attention to the comparison of prices between a predecessor and its successor. We denote a predecessor by a prime ($'$) and the price of a predecessor at entry (birth) by $p(t'_b)$, that of a predecessor at exit (death) by $p(t'_d)$, and that of a successor at entry (rebirth) by $p(t_b)$. For each product, we then calculate the difference between the price at death and the price at birth for the predecessor (calculated as $\ln p(t'_d) - \ln p(t'_b)$), the difference between the successor's price at birth and the predecessor's price at death ($\ln p(t_b) - \ln p(t'_d)$), and the successor's and predecessor's price at birth ($\ln p(t_b) - \ln p(t'_b)$), and aggregate these across products. Because of the large heterogeneity among products, we report the median of the aggregated price changes rather than the mean. The top panel of Figure 9 plots developments in theses price differences, with the horizontal axis representing the year in which a product was destroyed in the case of $\ln p(t'_d) - \ln p(t'_b)$ or reborn in the other two cases.

The price difference $\ln p(t'_d) - \ln p(t'_b)$ depicted by the red line with circles is negative, indicating that products tended to experience a price decline over their life span. The line starts near zero in the early 1990s and decreases gradually to about 10%. This indicates that the size of price declines over the life span of a product increased as deflation became more entrenched.

The price of a new product at entry exceeds that of its predecessor at exit, as is shown by the positive $\ln p(t_b) - \ln p(t'_d)$ represented by the black line with squares. The price of a successor product at birth is about 10% higher than that of the predecessor product at death.

Finally, the blue line with triangles representing $\ln p(t_b) - \ln p(t'_b)$ indicates that, from about 2000 onward, the price of a new product at birth is more or less equal to that of its predecessor at birth. Taken together, these results suggest the following price pattern under deflation: after a product is born, its price falls and at some point the product is destroyed; the successor is then introduced at the same price as the predecessor at birth.

This pattern under deflation is quite different from that observed under inflation in the early 1990s. For the early 1990s, the blue line with triangles representing $\ln p(t_b) - \ln p(t'_b)$ is positive. In other words, when the overall CPI inflation rate was relatively high at about 3%, successors' prices tended to be higher than those of their predecessors. This seems to be a natural result under inflation and is in line with the price pattern for durable goods such as automobiles documented by Bils (2009) for the United States. However, this does not mean that the opposite pattern – namely, that the price of a new product at entry is below that of its predecessor at entry – can be observed in Japan during the period of deflation. Rather, there appear to be factors that prevent the price of a successor at entry falling below that of its predecessor at entry despite deflation, making the "rebirth price" sticky and creating asymmetry in the price setting for new products under inflation and deflation.

This raises the question what factors are responsible for the stickiness of rebirth prices. An immediate candidate is quality improvements. If firms improve the quality of their product, this provides a justification for a higher price level. However, it is difficult to explain why the rebirth price equals the original birth price: it implies that the improvement in quality would have to exactly offset the price decline of the predecessor. Since this seems unlikely, another factor might be at play, namely, the fashion effect. Firms may be trying to attract consumers simply by introducing a new product, where the newness of the product is used as justification for the higher price. Finally, the fact that the price of a product returns to its previous level may be due to frictions, behavioral reasons, or irrationality on the part of firms or households.

Which of these factors matter? This question can be addressed by looking at quantities purchased as well as prices. Suppose the price of a product increases. The quality improvement and fashion effects raise consumer demand for the product, while a price rise simply reflecting the firm's intention to bring the product price back up to its previous level would decrease demand. The quantity data in our scanner data are useful to determine which of these factors likely is at play. The lower panel of Figure 9 plots developments in the difference of quantities sold of predecessor and successor products in a similar way to the top panel. Specifically, we denote the quantity of the predecessor purchased at entry (birth) by $q(t'_b)$, that of the predecessor at exit (death) by $q(t'_d)$, and that of the successor at entry (rebirth) by $q(t_b)$. We then calculate quantity differences as $\ln q(t'_d) - \ln q(t'_b)$, $\ln q(t_b) - \ln q(t'_d)$, and $\ln q(t_b) - \ln q(t'_b)$. The black line with squares is for $\ln q(t_b) - \ln q(t'_d)$ and shows that the quantity of new products purchased at entry is about $e^{0.5} - 1 \sim 36\%$ larger than that of the predecessor products purchased at exit. The quantity difference $\ln q(t'_d) - \ln q(t'_b)$ shown by the red line with circles is consistently negative at -0.5, suggesting that over the life span of a product the quantity purchased declines by about 36%. Finally, the blue line with triangles for $\ln q(t_b) - \ln q(t'_b)$ is stable around zero, suggesting that the quantity sold of a successor at entry is almost the same as that of its predecessor at entry.

This result suggests that firms can recover the price decline in their old product and bring the price back to the original level, since the successor at entry attracts greater demand than the predecessor at exit despite the higher price. In other words, consumers gain greater utility due to, for example, an improvement in quality or the fashion effect, contributing to a decrease in the welfare-based price index (COLI).

Stylized Fact 5:
The demand increase at entry is transitory and decays to a half in a month.

In the lower panel of Figure 9 we saw that new products attract higher demand even though they have a higher price than their predecessor. The immediate question is how persistent the demand increases at entry are. If the quality improvement effect dominates the fashion effect, one would expect demand increases to be more long-lived. To examine whether this is the case, in Figure 10, we plot the price and quantity changes of products after entry, with the horizontal axis representing the number of months since a product was created. The axis starts with zero for the month of product creation ($t = 0$). Note that the number of products decreases over time because of product exit from the market. The upper panel shows that product prices gradually decrease after entry, which is in line with Figure 9. The lower panel shows that, despite this price pattern, quantity also decreases over time. Furthermore, the decrease is quite drastic: the quantity sold drops to a half in the following month ($t = 1$) and to about 20% of the initial value after about half a year ($t = 6$). Comparing the two lines in the lower panel, we find that this transitory effect is larger in the period from 2000 to 2013 than that from 1988 to 1999.

This result supports the argument that fashion effects are at play. As assumed by Bils (2009) in his model, new products attract consumers simply because they are new, but this fashion effect decays over time. An illustrative example of the fashion effect is "limited" products. In Japan, manufacturers sell many types of products with a "limited" label indicating that the product is available only in a particular region and/or at a particular time. For example, one type of potato chips has a butter soy sauce flavor and is sold only in Hokkaido prefecture, which is famous for butter. Moreover, products are often "limited" in that they are sold only for a limited time, such as spring. Such limited products have gained huge popularity in Japan. Indeed, as Figure 11 shows, the number of products with the word "limited" (*gentei* in Japanese) in the name has increased rapidly. The popularity of such products can be seen as one reason product entry and exit rates are higher in Japan than in the United States.[5]

4 Model to Calculate the COLI with Product Turnover

In this section, we introduce a model to calculate the COLI, a welfare-based price index. The model takes account of the following four effects on the COLI. First, when the price of products that have the same characteristics changes, the COLI changes (the price effect in the matched sample). Because many products experience a price decline over their life span, as Figures 2 and 5 showed, this effect tends to decrease the COLI. Second, when the price of newly entering products differs from that of old exiting products, the COLI changes (the price effect at entry). If firms recover the price decline of their products by introducing new products, the COLI increases. Third, when the quality

[5]High and transitory demand at entry may also reflect that consumers try out new products to test their quality.

of newly entering products differs from that of old exiting products, the COLI changes (the quality effect). In particular, the higher the quality of newly entering products, the more the COLI declines. Fourth, when new products enter the market, household utility increases temporarily, which lowers the COLI (the fashion effect).

To calculate the COLI taking these four factors into account, we extend the model developed by Feenstra (1994), who incorporates product turnover with the quality improvement effect, to further incorporate the fashion effect examined by Bils (2009). See also Sato (1976), Diewert (1976), and Melser (2006) for the theoretical background of the COLI with product turnover.

The COLI is defined as the minimum cost of achieving a given utility, which we assume is expressed by the following constant elasticity of substitution (CES) function over a changing domain of products $i \in I_t$:[6]

$$C(p(t), I_t) = [\sum_{i \in I_t} c_i(t)]^{1/(1-\sigma)}, \tag{1}$$

where $c_i(t)$ represents the inverse of the cost associated with the purchase of product i in period t:

$$c_i(t) = \begin{cases} b_i \phi_i(t_i) \left[p_i(t)\right]^{1-\sigma} & \text{if } t_i < \tau \\ b_i \left[p_i(t)\right]^{1-\sigma} & \text{otherwise.} \end{cases} \tag{2}$$

Here, $\sigma > 1$ represents the elasticity of substitution, $p_i(t) > 0$ stands for the price of product i, $p(t)$ denotes its corresponding vector, and b_i represents the quality of or taste for product i.

The innovation in this specification compared to Feenstra (1994) is the introduction of the fashion effect $\phi_i(t_i)$, which increases household utility, where t_i represents time since the birth of a product. The elapsed time in the month of birth is zero. Bils (2009) assumes in his model that the fashion effect decays at a constant rate when a product is not renewed, while it jumps by a factor of 12 when a product is renewed after one year. Similar to Bils (2009), we assume that the fashion effect has a finite duration, but we do not need to assume any specific process regarding the speed of decay. Both a higher b_i and $\phi_i(t_i)$ increase utility and lower living cost $C(p(t), I_t)$ because of $\sigma > 1$. The difference between the two is that, while a quality improvement improves utility permanently as long as the product lasts, the fashion effect is transitory. Thus, all else

[6]To obtain this form, we need a homothetic CES utility function. See Lloyd (1975).

being equal, the fashion effect on the rate of change in the COLI is almost neutral, because it decreases the COLI at the entry of a product but increases it after τ periods, like the effect of temporary sales on the price index.[7]

As is well known, the CES function leads to the following convenient relationship:

$$\frac{p_i(t)q_i(t)}{\sum_{j\in I_t} p_j(t)q_j(t)} = \frac{c_i(t)}{\sum_{j\in I_t} c_j(t)}, \tag{3}$$

where $q_i(t)$ represents the quantity purchased of a product i in period t. See Appendix B for the proof. The left-hand side of equation (3) represents the sales share of a product i. Because the sales share is observable from our scanner data, this equation helps us to compute the COLI as well as quality and fashion effects.

4.1 The COLI with Quality Effects Only

As in Feenstra (1994), using equation (3), we can write a change in the COLI from $t-1$ to t as

$$\begin{aligned}
\frac{C(p(t),I_t)}{C(p(t-1),I_{t-1})} &= \frac{\left[\sum_{i\in I_t} c_i(t)\right]^{\frac{1}{1-\sigma}}}{\left[\sum_{i\in I_{t-1}} c_i(t-1)\right]^{\frac{1}{1-\sigma}}} \\
&= \left[\frac{\sum_{i\in I_t} c_i(t)}{\sum_{i\in I_{t-1}\cap I_t} c_i(t)} \times \frac{\sum_{i\in I_{t-1}\cap I_t} c_i(t)}{\sum_{i\in I_{t-1}\cap I_t} c_i(t-1)} \times \frac{\sum_{i\in I_{t-1}\cap I_t} c_i(t-1)}{\sum_{i\in I_{t-1}} c_i(t-1)}\right]^{\frac{1}{1-\sigma}} \\
&= \left[\frac{\sum_{i\in I_t} p_i(t)q_i(t)}{\sum_{i\in I_{t-1}\cap I_t} p_i(t)q_i(t)} \times \frac{\sum_{i\in I_{t-1}\cap I_t} c_i(t)}{\sum_{i\in I_{t-1}\cap I_t} c_i(t-1)} \times \frac{\sum_{i\in I_{t-1}\cap I_t} p_i(t-1)q_i(t-1)}{\sum_{i\in I_{t-1}} p_i(t-1)q_i(t-1)}\right]^{\frac{1}{1-\sigma}}.
\end{aligned} \tag{4}$$

Suppose for a moment that there is no fashion effect. Then, the second term in the right-hand side of equation (4) compares c_i in a common set, $i \in I_{t-1} \cap I_t$, which is called a *matched sample*. In the matched sample, the quality vector b does not change from $t-1$ to t, and hence, we can compute this term using the conventional method following Sato (1976) and Diewert (1976):

$$\left(\frac{\sum_{i\in I_{t-1}\cap I_t} c_i(t)}{\sum_{i\in I_{t-1}\cap I_t} c_i(t-1)}\right)^{\frac{1}{1-\sigma}} = \prod_{i\in I_{t-1}\cap I_t} \left(\frac{p_i(t)}{p_i(t-1)}\right)^{w_i(t)}, \tag{5}$$

[7] Another possible factor to explain the transitory demand for new products is seasonality. For example, ice cream is popular in summer, creating peak demand every 12 months. Such seasonality seems quantitatively small in our data because in Figure 10 there is little evidence of such a pattern where quantity increases about 12 months after entry.

where the cost share is $s_i(t) = p_i(t)q_i(t)/\sum_{j\in I_{t-1}\cap I_t} p_j(t)q_j(t)$ and the weight $w_i(t)$ is

$$w_i(t) = \frac{\left(\frac{s_i(t)-s_i(t-1)}{\ln s_i(t)-\ln s_i(t-1)}\right)}{\sum_{j\in I_{t-1}\cap I_t}\left(\frac{s_j(t)-s_j(t-1)}{\ln s_j(t)-\ln s_j(t-1)}\right)}. \tag{6}$$

The first term in the right-hand side of equation (4) represents the inverse ratio of the sales of the products in t that exist both in $t-1$ and t to those that exist in t. In other words, the inverse equals one minus the fraction of sales of newly born products in t to total sales in t.

The third term represents the ratio of the sales of products in $t-1$ that exist in both $t-1$ and t to those that exist in $t-1$. In other words, the ratio equals one minus the fraction of the sales of the products in $t-1$ that exit in t.

In sum, this equation illustrates that, as long as we know the sales shares of both newly entering and old exiting products, we can compute the rate of change in the COLI, without knowing the quality parameter b. This is the novel method developed by Feenstra (1994).

4.2 The COLI with Both Quality and Fashion Effects

We modify Feenstra's (1994) method to incorporate the fashion effect. In the presence of the fashion effect, the second term of the right-hand side of equation (4), $\sum_{i\in I_{t-1}\cap I_t} c_i(t)\Big/\sum_{i\in I_{t-1}\cap I_t} c_i(t-1)$, is no longer in a common set. For example, a newly born product i in $t-1$ attracts households by the fashion effect of $\phi_i(0)$ in $t-1$, which changes to $\phi_i(1)$ in t. Therefore, we cannot simply apply the conventional method of using a matched sample to this case.

The key to resolving this problem is a selection of the true common set of $i \in I_{t-\tau-1}\cap I_{t-1}\cap I_t$. Using equation (3), we have

$$\begin{aligned}
&\frac{C(p(t),I_t)}{C(p(t-1),I_{t-1})} = \frac{\left[\sum_{i\in I_t} c_i(t)\right]^{\frac{1}{1-\sigma}}}{\left[\sum_{i\in I_{t-1}} c_i(t-1)\right]^{\frac{1}{1-\sigma}}}\\
&= \left[\frac{\sum_{i\in I_t} c_i(t)}{\sum_{i\in I_{t-\tau-1}\cap I_{t-1}\cap I_t} c_i(t)} \times \frac{\sum_{i\in I_{t-\tau-1}\cap I_{t-1}\cap I_t} c_i(t)}{\sum_{i\in I_{t-\tau-1}\cap I_{t-1}\cap I_t} c_i(t-1)} \times \frac{\sum_{i\in I_{t-\tau-1}\cap I_{t-1}\cap I_t} c_i(t-1)}{\sum_{i\in I_{t-1}} c_i(t-1)}\right]^{\frac{1}{1-\sigma}}\\
&= \left[\frac{\sum_{i\in I_t} p_i(t)q_i(t)}{\sum_{i\in I_{t-\tau-1}\cap I_{t-1}\cap I_t} p_i(t)q_i(t)} \times \frac{\sum_{i\in I_{t-\tau-1}\cap I_{t-1}\cap I_t} c_i(t)}{\sum_{i\in I_{t-\tau-1}\cap I_{t-1}\cap I_t} c_i(t-1)} \times \frac{\sum_{i\in I_{t-\tau-1}\cap I_{t-1}\cap I_t} p_i(t-1)q_i(t-1)}{\sum_{i\in I_{t-1}} p_i(t-1)q_i(t-1)}\right]^{\frac{1}{1-\sigma}}.
\end{aligned} \tag{7}$$

As for the second term of the right-hand side, both the numerator and the denominator lie in the matched sample. The quality and fashion effects influence the numerator in exactly the same manner as the denominator, because the products are in $i \in I_{t-\tau-1} \cap I_{t-1} \cap I_t$ and thus born at or before $t-\tau-1$. Therefore, this term can be calculated by the conventional method using the matched sample.

The choice of the common set $i \in I_{t-\tau-1} \cap I_{t-1} \cap I_t$ modifies the first and third terms slightly. The inverse of the first term represents one minus the fraction of sales of products in period t that are born from period $t-\tau$ to t. The third term represents one minus the fraction of sales of products in period $t-1$ that are born from period $t-\tau$ to $t-1$ or exit in period t.

Special Case

As a special case, suppose

$$\frac{\sum_{i \in I_{t-\tau-1} \cap I_{t-1} \cap I_t} p_i(t-1) q_i(t-1)}{\sum_{i \in I_{t-\tau-1} \cap I_{t-1} \cap I_t} p_i(t) q_i(t)} = \frac{\sum_{i \in I_{t-1} \cap I_t} p_i(t-1) q_i(t-1)}{\sum_{i \in I_{t-1} \cap I_t} p_i(t) q_i(t)}.$$

If this holds for all $\tau = 1, 2, \cdots$, we can regard the fashion effect as continuing for an infinite period like a permanent improvement in quality and, in effect, to not exist. In this case, equation (7) reduces to Feenstra's (1994) equation, that is, equation (4), except for the difference in the matched sample in the second term.

Comparison with Redding and Weinstein (2016)

Redding and Weinstein (2016) propose a "unified approach" to calculating the COLI under time-varying demand, which corresponds to the time-varying fashion effects in our model. In their model, they introduce a more general form of $c_i(t)$ defined as $c_i(t) = [p_i(t)/\varphi_i(t)]^{1-\sigma}$, where $\varphi_i(t)$ captures time-varying shifts in demand for product i. Like us, they point out that the second term in (4) is not in a common set under time-varying demand and consequently rewrite it as follows:

$$\ln\left(\frac{\sum_{i \in I_{t-1} \cap I_t} c_i(t)}{\sum_{i \in I_{t-1} \cap I_t} c_i(t-1)}\right) = \ln\left(\frac{\widetilde{p(t)}^*}{\widetilde{p(t-1)}^*}\right) + \frac{1}{1-\sigma}\ln\left(\frac{\widetilde{s(t)}^*}{\widetilde{s(t-1)}^*}\right) - \ln\left(\frac{\widetilde{\varphi(t)}^*}{\widetilde{\varphi(t-1)}^*}\right), \tag{8}$$

where the geometric average $\widetilde{x(t)}^* \equiv \left(\Pi_{i \in I_{t-1} \cap I_t} x_i(t)\right)^{1/N_{t,t-1}}$ and $N_{t,t-1}$ indicates the number of goods in $I_{t-1} \cap I_t$. Note that time-varying demand $\widetilde{\varphi(t)}^*$ is unobservable.

They then assume that the geometric average of demand shifts is zero, that is,

$$\ln\left(\frac{\widetilde{\varphi(t)}^*}{\widetilde{\varphi(t-1)}^*}\right) = 0. \tag{9}$$

Now we can easily calculate the COLI, because the first and second terms in the right-hand side of equation (8) are observable.

Their model is complementary to ours in that it is very similar but uses different assumptions. We assume that for all products demand shifts stop varying after a finite period τ, while Redding and Weinstein (2016) assume no demand change on average. Which assumption is more appropriate depends on economic circumstances. For Japan, however, we believe that the scanner data support our estimation strategy, because we observe secular changes in pricing and product cycles even at an aggregate level, which runs counter to assumption (9). Moreover, Figure 10 shows that the spike in demand following the introduction of a new product that replaces an older one is short-lived and runs out after about half a year, which is consistent with our assumptions regarding the fashion effect.

4.3 Estimating the Quality and Fashion Effects

To calculate the inflation rate based on the COLI, we do not need to know the size of the quality and fashion effects. Nevertheless, they are very informative variables, so that we develop a method to estimate them by extending Feenstra (1994).

Intuitively, the approach we take is to identify the quality change $b_i/b_{i'}$ by comparing the sales share in the period when an old product i' exits the market and when its successor product i exits the market. Because the fashion effect disappears after a while following a product's entry, the difference in the sales shares provides an indication of differences in their quality, provided we properly take a number of other factors into account.

We identify both the level of and rate of change in the fashion effect. To estimate the level, that is, $\phi_i(0)$, we compare the sales share of product i at the time of entry and exit. Because the same product naturally has the same quality, the difference in the sales share represents the fashion effect. In addition, we calculate the rate of change in the fashion effect, $\phi_i(0)/\phi_{i'}(0)$, to compare it with the quality change, $b_i/b_{i'}$. We estimate the rate of change in the fashion effect by comparing the sales share between the period when an old product i' enters the market and when the successor product i enters the market. At entry, product prices reflect both the quality and fashion effects, so the difference in the sales share implies $(b_i\phi_i(0))/(b_{i'}\phi_{i'}(0))$. Using the quality change that we previously obtained, we can estimate the rate of change in the fashion effect.

Quality Effect

Let us start by explaining more detail how we estimate the quality effect. We assume that all products exit from the market at least τ periods after their entry.[8] In that case, product i exits from the market in period t_d without the fashion effect, i.e., $c_i(t_d) = b_i\left[p_i(t_d)\right]^{1-\sigma}$. Similarly, suppose that its predecessor i' exits in t'_d without the fashion effect, i.e., $c_{i'}(t'_d) = b_{i'}\left[p_{i'}(t'_d)\right]^{1-\sigma}$. Using equation (3) for t_d and t'_d, we have

$$\frac{p_i(t_d)q_i(t_d)}{\sum_{j\in I_{t_d}\cap I_{t'_d-\tau}} p_j(t_d)q_j(t_d)} = \frac{c_i(t_d)}{\sum_{j\in I_{t_d}\cap I_{t'_d-\tau}} c_j(t_d)}$$

and

$$\frac{p_{i'}(t'_d)q_{i'}(t'_d)}{\sum_{j\in I_{t_d}\cap I_{t'_d-\tau}} p_j(t'_d)q_j(t'_d)} = \frac{c_{i'}(t'_d)}{\sum_{j\in I_{t_d}\cap I_{t'_d-\tau}} c_j(t'_d)}.$$

We choose the matched sample, $I_{t_d}\cap I_{t'_d-\tau}$, to compare c_j. Dividing the former equation by the latter yields

$$\frac{b_i}{b_{i'}} = \left[\frac{\frac{p_i(t_d)q_i(t_d)}{\sum_{j\in I_{t_d}\cap I_{t'_d-\tau}} p_j(t_d)q_j(t_d)}}{\frac{p_{i'}(t'_d)q_{i'}(t'_d)}{\sum_{j\in I_{t_d}\cap I_{t'_d-\tau}} p_j(t'_d)q_j(t'_d)}}\right]\left[\frac{p_{i'}(t'_d)}{p_i(t_d)}\right]^{1-\sigma}\left[\frac{\sum_{j\in I_{t_d}\cap I_{t'_d-\tau}} c_j(t_d)}{\sum_{j\in I_{t_d}\cap I_{t'_d-\tau}} c_j(t'_d)}\right]. \tag{10}$$

All the terms in the right-hand side of the equation are observable from our scanner data. Hence, we can estimate quality change $b_i/b_{i'}$.

Fashion Effect

Next, we estimate the rate of change in the fashion effect. If we assume that product i enters the market in period t_b with $c_i(t_b) = b_i\phi_i(0)\left[p_i(t_b)\right]^{1-\sigma}$ and its predecessor i' enters in t'_b with $c_{i'}(t'_b) = b_{i'}\phi_{i'}(0)\left[p_{i'}(t'_b)\right]^{1-\sigma}$, employing the same method as above yields

$$\frac{b_i\phi_i(0)}{b_{i'}\phi_{i'}(0)} = \left[\frac{\frac{p_i(t_b)q_i(t_b)}{\sum_{j\in I_{t_b}\cap I_{t'_b-\tau}} p_j(t_b)q_j(t_b)}}{\frac{p_{i'}(t'_b)q_{i'}(t'_b)}{\sum_{j\in I_{t_b}\cap I_{t'_b-\tau}} p_j(t'_b)q_j(t'_b)}}\right]\left[\frac{p_{i'}(t'_b)}{p_i(t_b)}\right]^{1-\sigma}\left[\frac{\sum_{j\in I_{t_b}\cap I_{t'_b-\tau}} c_j(t_b)}{\sum_{j\in I_{t_b}\cap I_{t'_b-\tau}} c_j(t'_b)}\right]. \tag{11}$$

Once we know the quality change $b_i/b_{i'}$, we can estimate the rate of change in the fashion effect at entry, $\phi_i(0)/\phi_{i'}(0)$.

To estimate the level of the fashion effect, we assume that product i enters the market in period t_b with $c_i(t_b) = b_i\phi_i(0)\left[p_i(t_b)\right]^{1-\sigma}$ and exits in period t_d with $c_i(t_d) = b_i\left[p_i(t_d)\right]^{1-\sigma}$, where $t_d - t_b \geq \tau$. Then, the same computation yields the level of the fashion effect:

[8] Instead of this assumption, we could limit products' life span to τ or longer when estimating the change in quality. However, doing this requires to choose an appropriate τ.

$$\phi_i(0) = \left[\frac{\frac{p_i(t_b)q_i(t_b)}{\sum_{j\in I_{t_d}\cap I_{t_b-\tau}} p_j(t_b)q_j(t_b)}}{\frac{p_i(t_d)q_i(t_d)}{\sum_{j\in I_{t_d}\cap I_{t_b-\tau}} p_j(t_d)q_j(t_d)}}\right] \left[\frac{p_i(t_d)}{p_i(t_b)}\right]^{1-\sigma} \left[\frac{\sum_{j\in I_{t_d}\cap I_{t_b-\tau}} c_j(t_b)}{\sum_{j\in I_{t_d}\cap I_{t_b-\tau}} c_j(t_d)}\right]. \tag{12}$$

5 Applying the Model to Japan

In this section, we apply the above model to Japan. We start by calculating time-series changes in the COLI. Next, we examine the size of quality and fashion effects.

We employ the following parameters. We set the elasticity of substitution σ to 11.5 based on Broda and Weinstein's (2010) estimate, although they mention that the demand elasticity typically lies between 4 and 7. However, we find that changing σ leaves our results essentially unchanged, at least qualitatively. As for the duration of the fashion effect τ, we set a value of 7 based on the bottom panel of Figure 10. We show how using different values for τ changes the COLI below.

5.1 Price Index

Figure 12 plots the COLI over time. The line with triangles shows the COLI based on Feenstra's method, that is, equation (4), where the set of $I_{t-1} \cap I_t$ is treated as a matched sample. The line with circles shows the COLI using our method, that is, equation (7), where the set of $I_{t-\tau-1} \cap I_{t-1} \cap I_t$ is treated as a matched sample. The thin line represents the inflation rate of the matched sample that corresponds to the second term of equation (7). While not shown in the figure to avoid it getting too cluttered, the inflation rate of the matched sampled based on Feenstra's method is very close to the thin line.

The annual inflation rate for the matched sample is slightly negative and is very close to the official CPI inflation rate. In contrast, the inflation rate based on the COLI constructed using Feenstra's method is much lower, fluctuating around -10% annually. As a result, the inflation rate based on Feenstra's method turns out to be consistently lower than that calculated for the matched sample. To understand why this happens, it is important to note that Feenstra's model assumes that high demand for a new product comes only from an improvement in quality if the price remains unchanged. Therefore, an increase in the market share of a product at the time of its entry to the market is always regarded as an indication of a quality improvement. Our finding in Figure 12 indicates that the quality improvement measured based on Feenstra's assumption exceeds the extent to which firms recover the price decline of the predecessor product when they introduce a new product. Similar findings are obtained in previous studies including Broda and Weinstein (2010) and Melser (2006).

However, this result does not hold for the COLI based on our extended model. Figure 12 shows that incorporating the fashion effect eliminates the deflationary effect of changes in quality. The line with circle moves in parallel with the line with triangles but lies above it. In other words, Feenstra's method overestimates deflation. Intuitively, this difference arises because the fashion effect on the COLI is transitory, while the effect of quality changes is permanent. The fashion effect of new product i at time t on the COLI is deflationary from t to $t + \tau - 1$, but disappears after $t + \tau$. Thus, the fashion effect reduces the change in the COLI at time t but increases it at time $t + \tau$. The difference in the annual inflation rate between Feenstra's model and ours is about 10 percentage points. Comparing the inflation rate suggested by our model and that by the matched sample suggests that the latter is a good approximation of the COLI. In other words, the quality and fashion effects on the COLI are almost equal in size to those of firms' efforts to recover the price decline at entry.

Although the COLI generally moves in tandem with the inflation rate of the matched sample, a gap seems to open up around the year 2000. The former is slightly higher than the latter, suggesting that the downward effects of quality and fashion on the COLI are smaller than the upward effect of firms' price recovery efforts.

To examine the robustness of our results to the choice of τ, in Figure 13 we plot the inflation rates of the matched sample and the COLI using different values for τ in addition to 7, namely, 1, 3, and 15. We find that as τ increases, the inflation rate of the matched sample slightly increases. This reflects what we found in Figure 8, namely, that longer-lived products tend to experience higher inflation rates. The larger τ is, the more is the matched sample dominated by longer-lived products, which increases the inflation rate of the matched sample. The COLI also increases as τ increases. Most notably, for the shortest life span, when τ equals 1, the inflation rate of the COLI is below that of the matched sample, unlike in the other three cases. Because in this case a demand increase that lasts for more than a month is regarded as a quality change rather than the result of the fashion effect, the COLI decreases the most. The inflation rate of this COLI lies between the inflation rate of the matched sample and that based on the COLI obtained using Feenstra's method shown in Figure 12. On the other hand, as τ increases, the inflation rate of the COLI increases, but the results using $\tau = 3$, 7, and 15 are very similar.

5.2 Quality and Fashion Effects

Using the method outlined in Section 4.3, we compute the size of the quality and fashion effects for Japan. To do so, we link product predecessors and successors at the 3-digit code (product category) level as explained in Section 2. It is not necessary to link predecessors and successors for each product, as we discuss in Appendix C. We estimate the size of the quality and fashion effects at the product category level for each month and then calculate the mode. The results are shown in Figures 14 and 15.

Quality Effect

The upper panel of Figure 14 shows the density function of the rate of change in quality estimated from equation (10). The horizontal axis represents $b_i/b_{i'}$, where a value above one represents an increase in quality and vice versa. The vertical axis represents the number of product categories. The density peaks at one, meaning that product quality remained more or less unchanged at entry. Because the distribution is skewed to the right, some products seem to have experienced significant quality improvements, while other products experienced a moderate quality deterioration.

The lower panel shows the rate of aggregated quality changes over time. On average, it exceeds one, but it slightly declined over the two decades from about 1.4 to 1.1.[9] This, together with the findings obtained earlier, suggests that as the number of products introduced into the market increased, the improvement in quality with each new product declined. The decline in the rate of change in quality has resulted in upward pressure on the rate of change in the COLI.

Fashion Effect

Next, the upper panel of Figure 15 shows the density function of the rate of change in the fashion effect estimated from equation (11). The distribution of $\phi_i(0)/\phi_{i'}(0)$ is skewed to the right, while the mode of $\phi_i(0)/\phi_{i'}(0)$ is around one. The middle panel shows

[9]The figure shows that in 2002 there is a spike in the rate of change in quality, but this likely is due to missing data for November and December 2003.

developments in the rate of change in the fashion effect over time. The graph shows that the rate of change has been declining over time, which is similar to the rate of change in quality. Let us consider the implications for the COLI. It is important to note that the fashion effect on the COLI is almost neutral because of its transitory nature. However, combined with the increase in the number of products, the fashion effect exerts downward pressure on the level of the COLI. Thus, it is likely that the decline in the rate of change in the fashion effect has exerted upward pressure on the rate of change in the COLI.

Finally, the lower panel shows developments in the aggregated fashion effect computed from equation (12). The estimated $\phi_i(0)$ exceeds one, suggesting considerable fashion effects. Because the rate of change in the fashion effect exceeds one on average, as shown in the middle panel, the level of the fashion effects keeps increasing during the observation period.[10]

This increase in the fashion effects is consistent with the increasing popularity of "limited" products that we showed in Figure 11. While our analysis cannot tell us whether the reason for the increase in "limited" products is that consumers' taste for such products increased or, alternatively, firms realized that there was latent demand for such products and they responded by offering more of such products, the increased offering of such products appears to be an important strategy by firms to raise sales under deflation.

6 Concluding Remarks

In this study, we documented the pattern of product turnover in Japan and examined its effect on a welfare-based price index, namely, the COLI. Three particularly important findings of our analysis are as follows. First, an increasing fraction of products experienced a price decline over their life span as deflation became increasingly entrenched. Second, firms tend to use successor products to recover the price decline. And third, the increase in demand when a new product replaces an old product is transitory and decays to half within a month.

Our model incorporates not only quality but also fashion effects. Our results are

[10]The changes in the quality and fashion effects over time conflict with Redding and Weinstein's (2016) assumption of no demand change on average.

as follows. First, we found a considerable fashion effect, while the effect of quality changes slightly declined during the lost decades. Second, the discrepancy between the COLI estimated based on our methodology and the price index constructed only from the matched sample is not large, although the COLI estimated based on Feenstra's (1994) methodology is significantly lower than the price index constructed only from the matched sample.

Our findings help to explain why Japan managed to avoid falling into a severe deflationary spiral. During the two lost decades, Japanese firms introduced many new products into the market to recover the decline in the price of predecessor products. Even though quality improvements slowed down, the strategy worked because consumers were willing to pay the higher price due to the fashion effect.

In the future, we are hoping to extend our work mainly in two directions. The first is to apply our method to other economies such as the United States and the Euro area. This would help us to understand whether our results are peculiar to Japan, which experienced deflation. Second, we did not consider carefully the reasons for the price setting we observed or the reasons why firms retire products frequently and replace them with similar new ones. Important factors likely are the zero lower bound on nominal interest rates and deregulation in the retail market. Matsuura and Sugano (2009) and Abe and Kawaguchi (2010), for example, show that government policies in the 1990s relaxing entry regulations encouraged large retailers to enter the market. Endogenizing product turnover and investigating the causality between product turnover and price setting are important topics to be examined in the future.

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A Aggregation of Variables and Identification of Product Entry and Exit

A.1 Aggregation

In this study, we aggregate variables of interest over days, products, and shops in the following way.

1. We aggregate a variable, such as the sales amount and quantities sold of each product, over shops.

2. We take the daily average of a variable by dividing it by the number of days in each month.

3. Aggregation over products

    (a) Except when calculating the COLI, we take the logarithm of a variable (unless it is a rate of change or ratio) and then aggregate the values over products, assigning equal weights to all products.

    (b) To construct the COLI, we use the formula explained in the main text for products in each 3-digit category. We then aggregate the COLI at the 3-digit category level using the sales weight.

The reason for aggregating over shops first is to mitigate chain drift. As highlighted by Feenstra and Shapiro (2003), the durability of goods and households' desire to hold inventories create considerable chain drift in the chained price index. Also see Ivancic, Diewert, and Fox (2011).

A.2 Identifying the Entry and Exit of Products

We explain how we identify the date of birth (entry) and death (exit) of a product. As for the former, after aggregating sales amounts and quantities sold over shops, we record the earliest date when a product was sold and denote this as the date of birth (entry) t_b. We then calculate its sales amounts and quantities sold per day by dividing sales and quantities by the remaining days of the month, that is, $t_m - t_b + 1$, where t_m represents the days of the month. This provides the quantity $q(t_b)$ per day in the month of birth (entry). The price $p(t_b)$ is computed by dividing sales per day by the quantity sold per day. We use posted prices, not regular or temporary sales prices.

Similarly, the date of death (exit) t_d is defined as the last date when a product was sold. Sales and quantities per day are calculated by dividing sales and quantities by t_d. This provides us with the quantity $q(t_d)$ per day and the price $p(t_d)$ in the month of death (exit). In other months of the product cycle, the quantity per day and the price are defined as the quantity sold divided by the days of the month and sales divided by the quantity sold, respectively.

B Proof of Equation (3)

Using Shephard's Lemma, we have the following equation for the quantity $q_i(t)$ sold of product i from equation (1):

$$\begin{aligned} q_i(t) = \frac{\partial C(p_t, I_t)}{\partial p_i(t)} &= \frac{1}{1-\sigma}\left[\sum_{i \in I_t} c_i(t)\right]^{\frac{1}{1-\sigma}-1} \frac{\partial c_i(t)}{\partial p_i(t)} \\ &= \frac{1}{1-\sigma} C(p_t, I_t)^{\sigma} A_i(t_i)(1-\sigma)\left[p_i(t)\right]^{-\sigma}, \end{aligned}$$

where $A_i(t_i)$ encompasses quality and fashion effects for product i, which are independent of $p_i(t)$. This yields

$$\begin{aligned} p_i(t) q_i(t) &= C(p_t, I_t)^{\sigma} A_i(t_i)\left[p_i(t)\right]^{1-\sigma} \\ &= c_i(t) C(p_t, I_t)^{\sigma}, \end{aligned}$$

leading to

$$\frac{p_i(t) q_i(t)}{c_i(t)} = C(p_t, I_t)^{\sigma}.$$

The right-hand side of the equation is independent of i, and we thus obtain equation (3).

C When Product Generations are not Tracked One-to-One

The model in the main text assumes full information on product generations: a product i' is known to be the predecessor of a product i. However, our scanner do not allow us to match product generations one-to-one for all products.

Nevertheless, we can still estimate the quality and fashion effects. To see this, we take the logarithm of equation (10):

$$\ln \frac{b_i}{b_{i'}} = \ln \frac{p_i(t_d) q_i(t_d)}{\sum_{j \in I_{t_d} \cap I_{t'_d - \tau}} p_j(t_d) q_j(t_d)} - \ln \frac{p_{i'}(t'_d) q_{i'}(t'_d)}{\sum_{j \in I_{t_d} \cap I_{t'_d - \tau}} p_j(t'_d) q_j(t'_d)}$$
$$+ (1-\sigma) \left[\ln p_{i'}(t'_d) - \ln p_i(t_d) \right] + \ln \left[\frac{\sum_{j \in I_{t_d} \cap I_{t'_d - \tau}} c_j(t_d)}{\sum_{j \in I_{t_d} \cap I_{t'_d - \tau}} c_j(t'_d)} \right].$$

The first and second terms in the right-hand side can be computed without one-to-one matching of product generations. Taking the average across products i and i', we have

$$\left\langle \ln \frac{b_i}{b_{i'}} \right\rangle = \left\langle \ln \frac{p_i(t_d) q_i(t_d)}{\sum_{j \in I_{t_d} \cap I_{t'_d - \tau}} p_j(t_d) q_j(t_d)} \right\rangle - \left\langle \ln \frac{p_{i'}(t'_d) q_{i'}(t'_d)}{\sum_{j \in I_{t_d} \cap I_{t'_d - \tau}} p_j(t'_d) q_j(t'_d)} \right\rangle$$
$$+ (1-\sigma) \left[\langle \ln p_{i'}(t'_d) \rangle - \langle \ln p_i(t_d) \rangle \right] + \left\langle \ln \left[\frac{\sum_{j \in I_{t_d} \cap I_{t'_d - \tau}} c_j(t_d)}{\sum_{j \in I_{t_d} \cap I_{t'_d - \tau}} c_j(t'_d)} \right] \right\rangle,$$

where $\langle z_i \rangle$ represents an operator to take the average of z_i across i. Even if the number of products i denoted by N differs from that of products i' denoted by N', the above equation holds true, as long as the probability that a product in i' changes to a product in i equals $1/N$.

Table 1: JAN Codes and Product Names of Margarine Made by Meiji Dairies

JAN codes	Product names
4902705092709	Meiji Corn Soft Half 120g
4902705100374	Meiji Corn Soft Half 120g
4902705066915	Meiji Corn Soft with Butter 400g
4902705104280	Meiji Corn Soft with Butter 300g
4902705001541	Meiji Corn Soft Fat Spread 225g
4902705001558	Meiji Corn Soft Fat Spread 450g
4902705100275	Meiji Corn Soft Fat Spread 180g
4902705100336	Meiji Corn Soft Fat Spread Box 400g
4902705105379	Meiji Corn Soft Fat Spread (Weight Increased) 320+20g
4902705106383	Meiji Corn Soft Fat Spread 160g

Table 2: Basic Statistics for Product Entry and Exit Rates

	Mean	S.D.	Min	Max	Processed food	Domestic articles	1988 –1999	2000 –2013
Entry rate	0.30	0.11	0.02	0.64	0.30	0.30	0.30	0.31
Exit rate	0.28	0.10	0.05	0.64	0.29	0.27	0.27	0.29

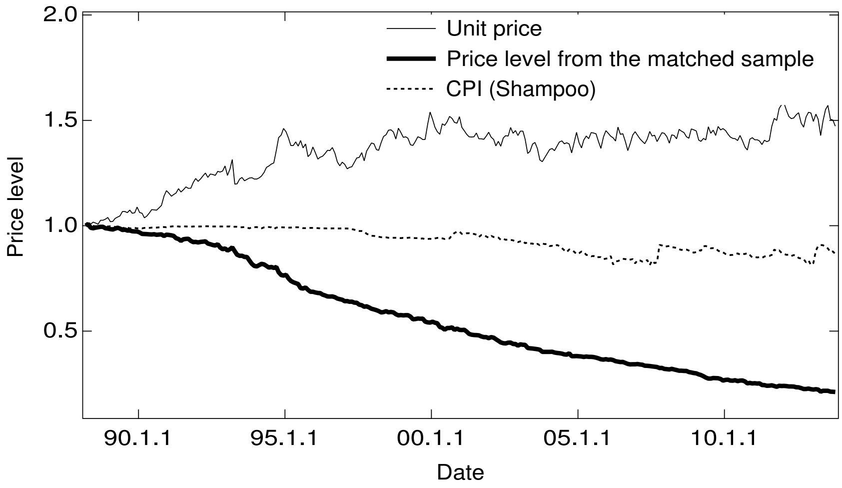

Figure 1: Prices of Shampoos

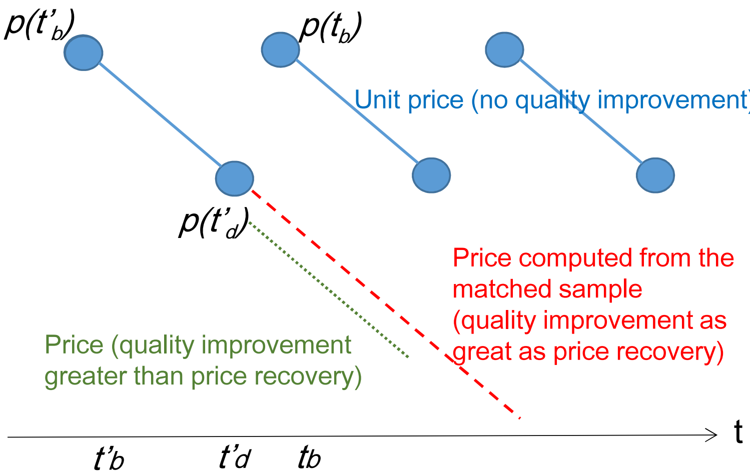

Figure 2: Pattern of Price Changes and Price Indexes

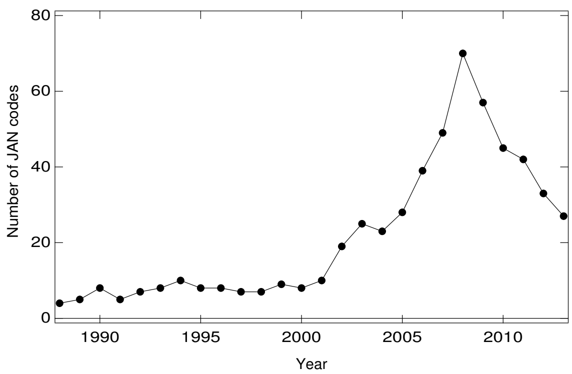

Figure 3: Number of “Kit Kat” Products

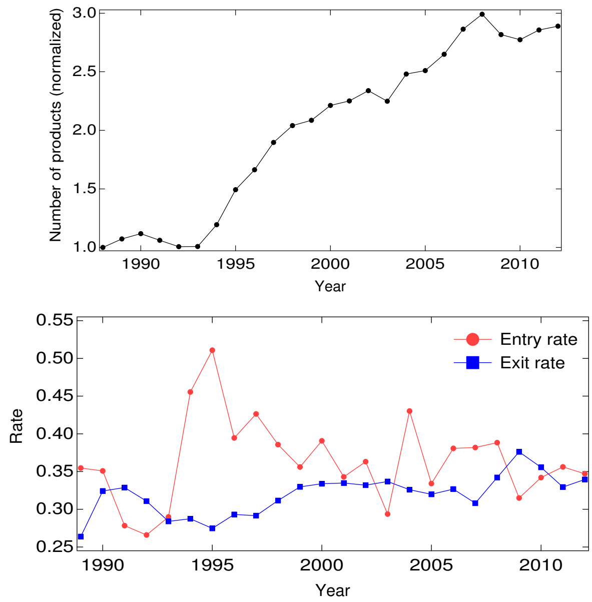

Figure 4: Number of Products (top) and Entry and Exit Rates (bottom)

Note: The number of products is normalized to one in 1988.

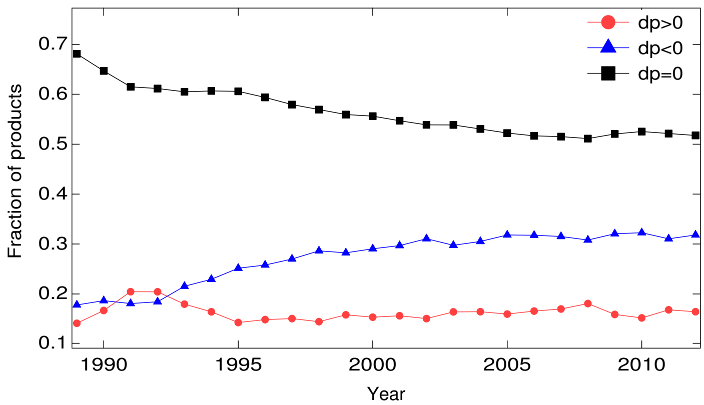

Figure 5: Fractions of Products whose Price Increases, Decreases, or Does Not Change Over their Life Span

The horizontal axis represents a year when the product was discontinued.

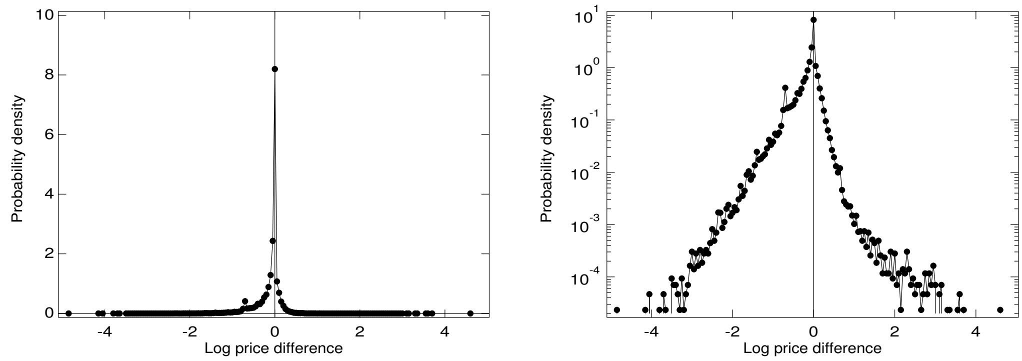

Figure 6: Probability Density Function of Price Changes over Product Life

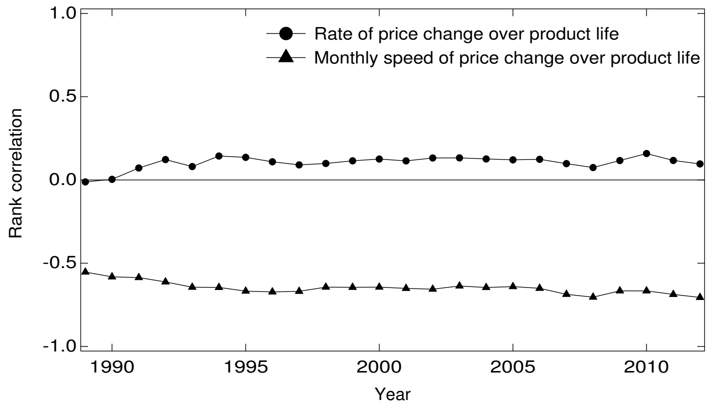

Figure 7: Correlation between the Life Span and the Rate of Price Change over Product Life

Note: The line with circles represents the correlation between the life span and the price change over the product's life in each year. The line with triangles represents the correlation between the life span and the monthly speed of price change over the product's life in each year. The horizontal axis represents a year when the product was discontinued.

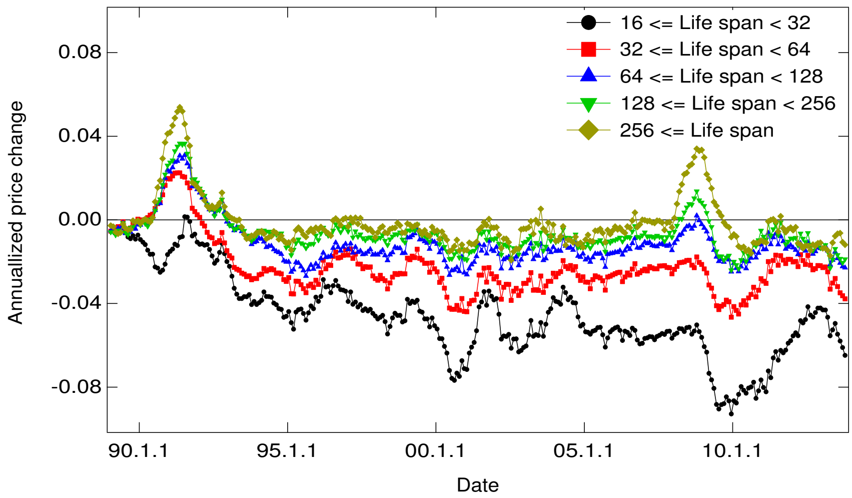

Figure 8: Annual Price Changes by Life Span

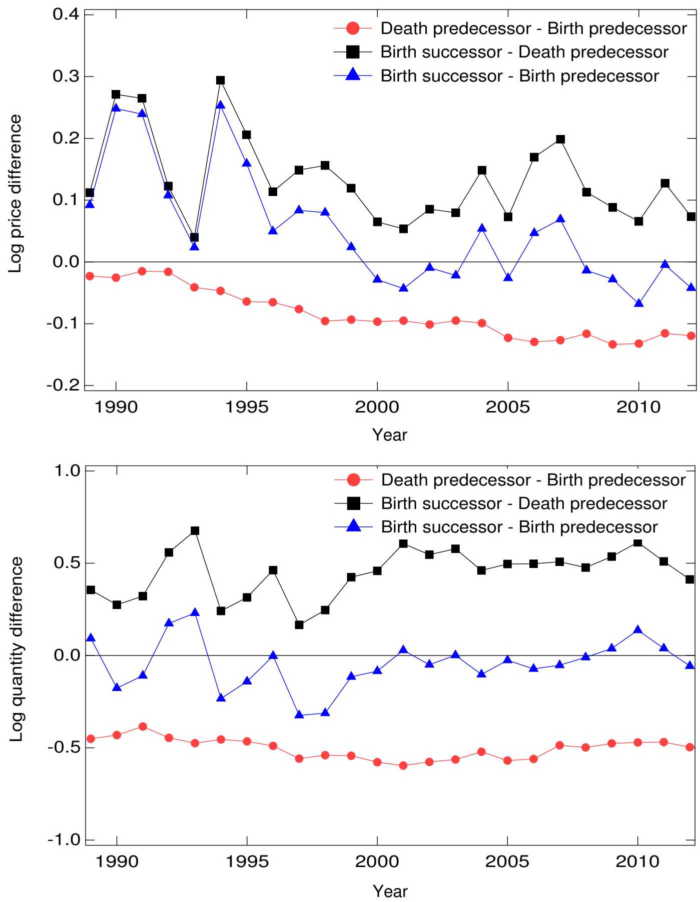

Figure 9: Price and Quantity Changes over the Product Cycle

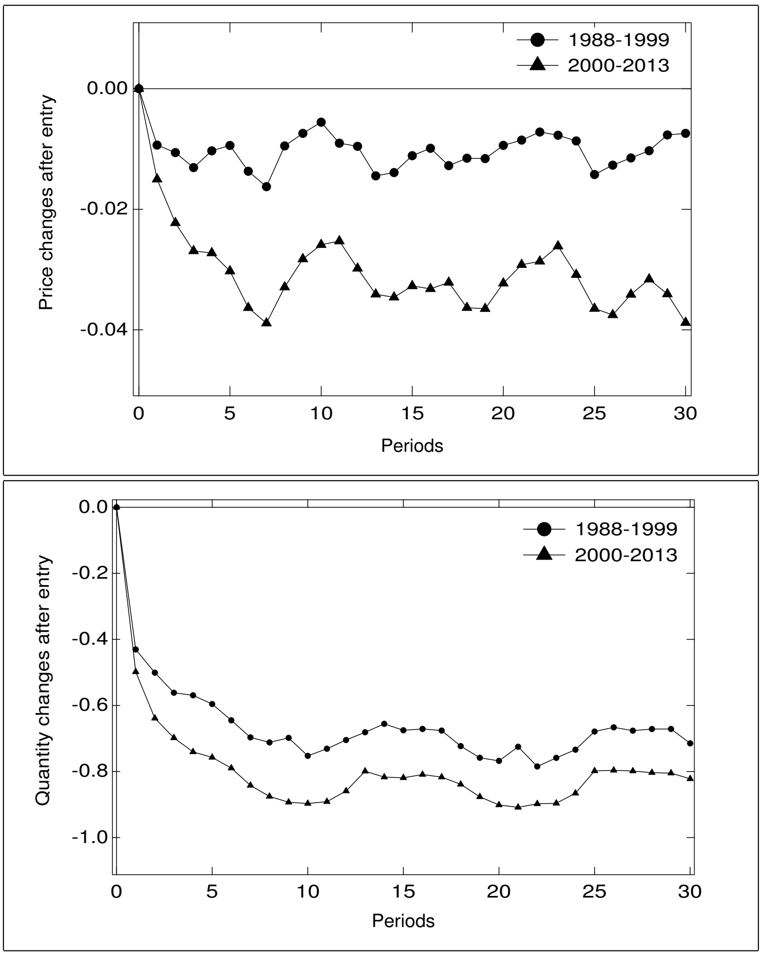

Figure 10: Price and Quantity Changes after Entry

Note: The horizontal axis represents the number of months since products were created.

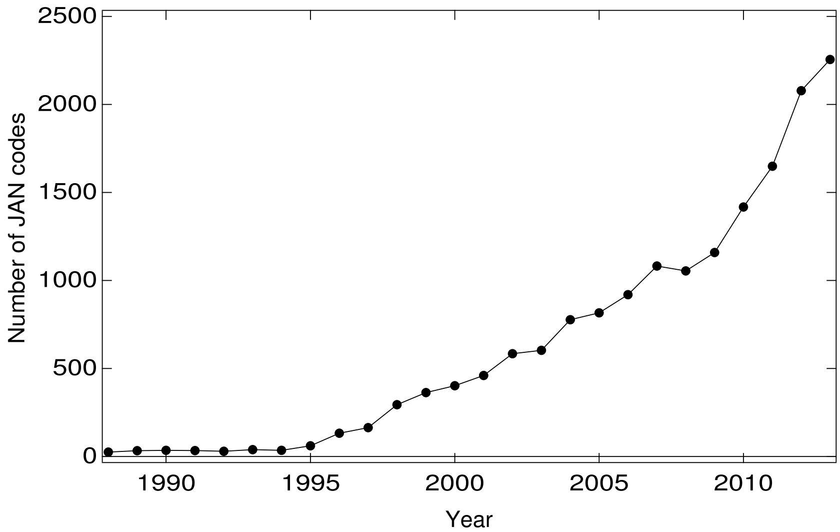

Figure 11: Number of “Limited” Products

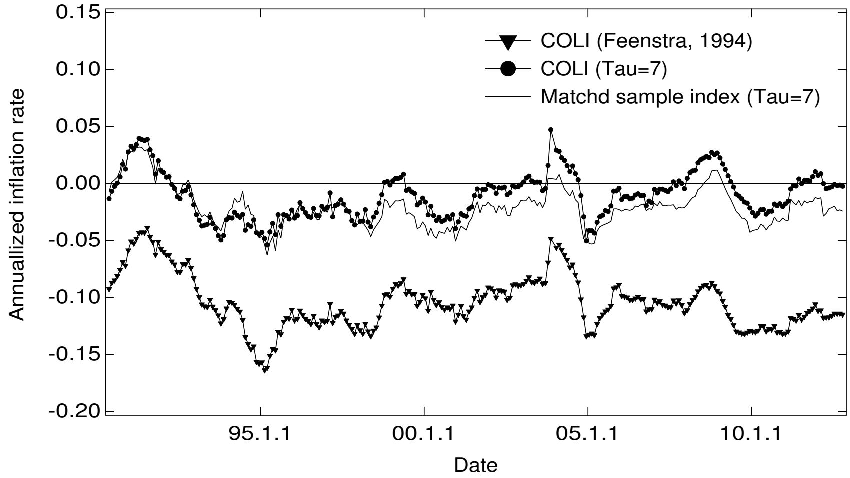

Figure 12: The Cost-of-Living Index (COLI)

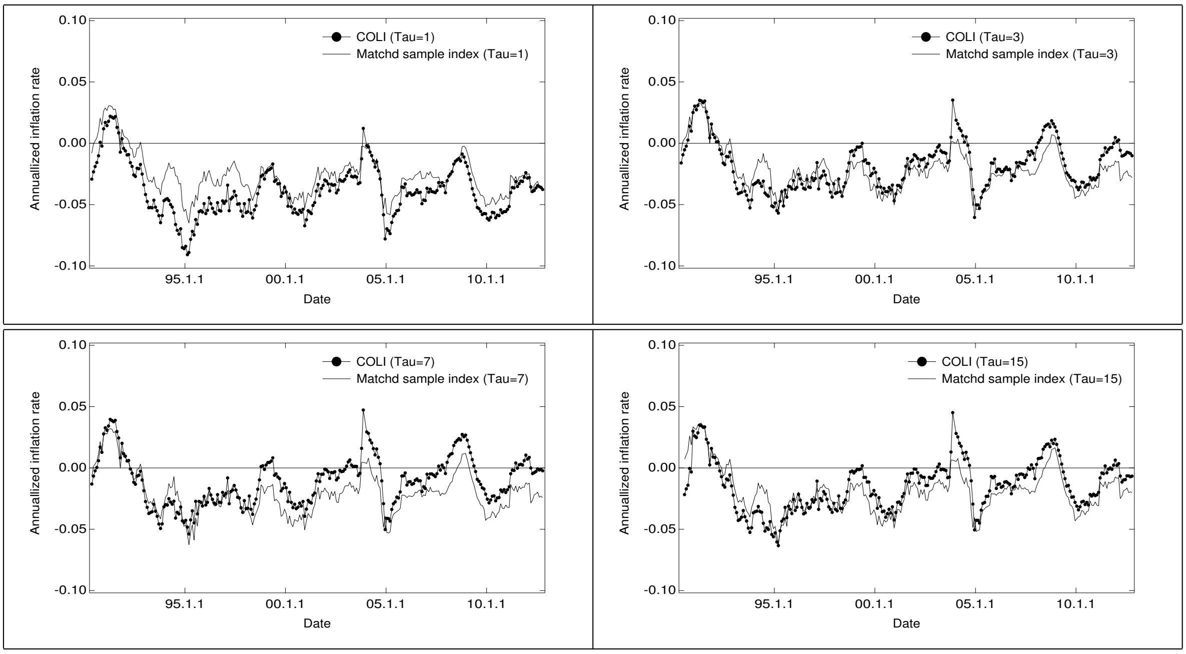

Figure 13: The COLI Under Different τ

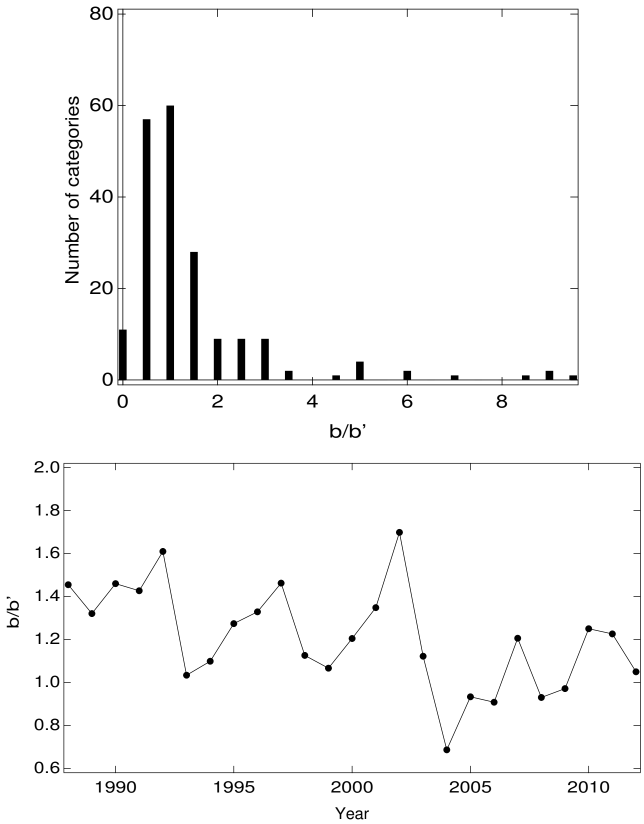

Figure 14: Quality Effect

Note: The upper panel shows the density function of changes in quality, while the lower panel shows developments in quality changes over time.

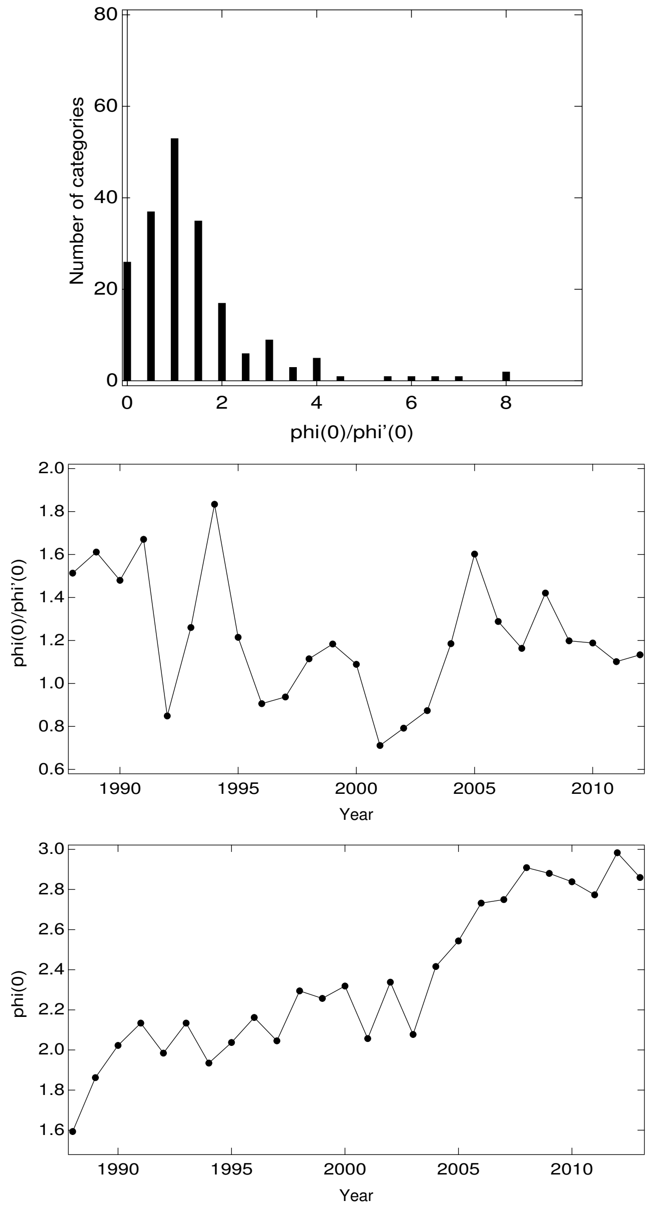

Figure 15: Fashion Effect

Note: The upper panel shows the density function of rates of change in the fashion effect, while the middle panel shows developments over time. The lower panel shows developments in the level of the fashion effect.