Quality-Adjusted Unit Value Index: Are Changes in Average Prices Inflation or Quality Change?

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The growing availability of digitized item-level transaction data has led to widespread use of average selling prices to track price changes within both narrowly and broadly defined product groups. Such measures are commonly used by retailers and market analysts as indicators of price trends. Examples of firms reporting average selling prices in levels or growth rates include Walmart, Amazon, Circana, Consumer Intelligence Research Partners, and NielsenIQ (see online appendix). The appeal of the average selling price lies in its simplicity: it is a timely measure of price movements based on the ratio of sales to units sold. It, however, does not provide a reliable measure of inflation unless the goods it covers are truly homogeneous. This paper derives and analyzes a decomposition of the change in average selling price into inflation and the effects of product heterogeneity. It shows that shifts in consumer demand toward higher-quality models explains much of the increase in average selling price of notebook computers.

I. Conceptual Framework

A. Decomposing the Change in Average Selling Price

The average selling prices for Ω_t, the basket of goods sold in time t, is

$$\mathbb{P}_t = \sum_{k\in\Omega_t} p_{kt}q_{kt} / \sum_{k\in\Omega_t} q_{kt} \tag{1}$$

where p_{kt} is the price and q_{kt} is the quantity item k in period t. The unit value index (UVI) is defined as the ratio of average selling prices across periods, that is,

$$\text{UVI} = \frac{\mathbb{P}_t}{\mathbb{P}_{t-1}}. \tag{2}$$

The numerator and denominator are each defined over the set of goods sold in their respective periods. These sets generally differ because of product entry and exit.

The UVI captures not only price changes for individual products, but also changes in the composition of goods sold. If consumers systematically shift their purchases toward continuing, entering, or exiting goods with different prices, the UVI may change even when the prices of individual goods remain constant.

We show that the UVI can be decomposed into a within-product component equal to a fixed-weight price index for continuing goods and a product mix component reflecting changes in the composition

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of products sold (see the online appendix for derivation). Specifically,

$$\frac{\mathbb{P}_t}{\mathbb{P}_{t-1}} = 1 + s^{\mathbb{C}}_{t-1} \sum_{k\in\mathbb{C}} s^{\mathbb{C}}_{kt-1}\left(\frac{p_{kt}}{p_{kt-1}} - 1\right) + \sum_{k\in\mathbb{C}} \Delta w_{kt}\left(\frac{p_{kt}}{\mathbb{P}_{t-1}}\right) + \sum_{k\in\mathbb{E}} w_{kt}\left(\frac{p_{kt}}{\mathbb{P}_{t-1}}\right) - \sum_{k\in\mathbb{X}} w_{kt-1}\left(\frac{p_{kt-1}}{\mathbb{P}_{t-1}}\right) \tag{3}$$

where $\mathbb{C}$, $\mathbb{E}$, and $\mathbb{X}$ denote the continuing goods between $t-1$ and t, and goods entering and exiting in t. The variable $s^{\mathbb{C}}_{k,t-1} = p_{k,t-1}q_{k,t-1} \big/ \sum_{k\in\mathbb{C}} p_{k,t-1}q_{k,t-1}$ denotes the expenditure share of item k among continuing goods in period $t-1$. The aggregate expenditure share of continuing goods in period $t-1$ is given by $s^{\mathbb{C}}_{t-1} = \sum_{k\in\mathbb{C}} p_{k,t-1}q_{k,t-1} \big/ \sum_{k\in\Omega_{t-1}} p_{k,t-1}q_{k,t-1}$. Similarly, the quantity share of item k in period t is $w_{kt} = q_{kt} \big/ \sum_{k\in\Omega_t} q_{kt}$; $\Delta w_{kt} = w_{kt} - w_{k,t-1}$ denotes the change in quantity shares between adjacent periods. The first term in the decomposition is a within term that is the growth rate from a standard matched-model arithmetic Laspeyres multiplied by the share of expenditures for continuing products. The next set of terms reflects changes in the product mix from continuing, entering, and exiting products. These product mix terms yield the gap between the UVI and this standard matched-model index. They will in general be non-zero, reflecting dispersion in prices across goods of different quality.[1]

This decomposition is of interest mainly because it makes precise the well-known limitation of the UVI in the presence of product quality heterogeneity. Addressing this limitation has led to the development of a quality-adjusted UVI (QUVI) given by

$$\text{QUVI} = \frac{P^{\tau}_t}{P^{\tau}_{t-1}} = \frac{\sum_{k\in\Omega_t} p_{kt}q_{kt} / \sum_{k\in\Omega_{t-1}} p_{kt-1}q_{kt-1}}{\sum_{k\in\Omega_t} \lambda^{\tau}_{kt}q_{kt} / \sum_{k\in\Omega_{t-1}} \lambda^{\tau}_{kt-1}q_{kt-1}} \tag{4}$$

where λ^{τ}_{kt} is the quality-adjustment factor, which standardizes units of quantity in terms of product quality for item k in period t. The index τ refers to the pairwise periods $(t-1,\ t)$ and $P^{\tau}_t = \sum_{k\in\Omega_t} p_{kt}q_{kt} / \sum_{k\in\Omega_t} \lambda^{\tau}_{kt}q_{kt}$. These adjustment factors can reflect simple differences in package size and weight, differences in observable characteristics, and differences in unobservable characteristics that relate to quality. A challenge, of course, is how to measure the quality-adjustment factors.

The QUVI also admits a decomposition that closely parallels that of the standard UVI. Specifically,

$$\text{QUVI} = 1 + s^{\mathbb{C}}_{t-1} \sum_{k\in\mathbb{C}} s^{\mathbb{C}}_{kt-1}\left(\frac{p_{kt}/\lambda^{\tau}_{kt}}{p_{kt-1}/\lambda^{\tau}_{kt-1}} - 1\right) + \sum_{k\in\mathbb{C}} \Delta w^{\tau}_{kt}\left(\frac{p_{kt}/\lambda^{\tau}_{kt}}{P^{\tau}_{t-1}}\right) + \sum_{k\in\mathbb{E}} w^{\tau}_{kt}\left(\frac{p_{kt}/\lambda^{\tau}_{kt}}{P^{\tau}_{t-1}}\right) - \sum_{k\in\mathbb{X}} w^{\tau}_{kt-1}\left(\frac{p_{kt-1}/\lambda^{\tau}_{kt-1}}{P^{\tau}_{t-1}}\right) \tag{5}$$

where $w^{\tau}_{kt} = \lambda^{\tau}_{kt}q_{kt} / \sum_{k\in\Omega_t} \lambda^{\tau}_{kt}q_{kt}$ denotes the quality-adjusted quantity weight for good k in period t, and $\Delta w^{\tau}_{kt} = w^{\tau}_{kt} - w^{\tau}_{kt-1}$ is its change. The interpretation of the terms in the QUVI are the same as in the UVI, but now adjusted for quality.

B. Using the QUVI to Bound Inflation

We introduce an approach to quality adjustment that builds on the insights of von Auer (2014) and de Haan (2015), who show that appropriate adjustment factors can yield bounds on the rate of inflation. We do so in an environment with product entry and exit using hedonic imputation.

We rely on the first-difference hedonic model of Erickson and Pakes (2011) as implemented in Ehrlich et al. (2025), which we refer to as EP-TV (see the online appendix for details). This ap-

[1] There are also antecedents to this decomposition in the literature. Balk (1998) relates the UVI to the Fisher index in an environment without product turnover. The online appendix has further discussion of the connection of our analysis with the literature.

proach defines the quality adjustment factors using a characteristic-constant convex combination of prices observed over adjacent periods. Adjustment factors are time-varying, allowing quantities to be normalized into quality-equivalent units on a period-by-period bilateral basis. For entering and exiting goods, it imputes price changes with the same approach. This approach allows us to define the quality-adjustment factors for all goods sold in either t and $t-1$ as

$$\begin{aligned} \lambda^{\tau}_{kt-1}(\alpha) &= \left(\widehat{p_{kt}/p_{kt-1}}\right)^{\alpha} \times p_{kt-1} \quad \text{for } k \in \Omega_{t-1} \\ \lambda^{\tau}_{kt}(\alpha) &= \left(\widehat{p_{kt}/p_{kt-1}}\right)^{-(1-\alpha)} \times p_{kt} \quad \text{for } k \in \Omega_{t} \end{aligned} \tag{6}$$

where $\widehat{p_{kt}/p_{kt-1}}$ is the predicted price relative from a first difference hedonic model estimated for the difference between $t-1$ and t using the EP-TV approach. We introduce the mixing parameter $\alpha \in [0,\ 1]$ that controls the weight placed on contemporaneous price versus the predicted price relative.

This framework yields quality-adjusted average prices with important bounding properties, that are most transparent for the two polar values of the mixing parameter: The QUVI is equal to the hedonic Paasche inclusive of entry when $\alpha = 0$ and the hedonic Laspeyres inclusive of exit where $\alpha = 1$ (see online appendix for formulas). Thus, the QUVI yields an upper and lower bound of the true cost-of-living (Konüs, 1939). As emphasized by Pakes (2003), Konüs bounds hold under very general assumptions. Lastly, bounds from hedonic indices tend to be tighter than the matched-model Laspeyres and Paasche indices (Erickson and Pakes, 2011 and Ehrlich et al., 2025). Moreover, we are able to generate interesting intermediate indices by taking the geo-mean of these bounds to produce a hedonic Fisher index or setting the mixing parameter $\alpha = 0.5$ to produce a hedonic Davies index (see Davies, 1924).

In summary, the proposed form of adjustment delivers a set of quality-adjusted unit value indices that are well defined in the presence of product entry and exit. These are full-imputation hedonic price indices using predicted price relatives for continuing, entering, and exiting goods, and as emphasized by Crawford and Neary (2023), they are characteristics-based price indices. The resulting bounds use only standard conditions underlying hedonic imputation and index-number theory.

II. Data and Estimation

We use proprietary data that the NPD Group (now part of Circana) provided to the U.S. Census Bureau. The database consists of point-of-sale (POS) information collected from thousands of brick-and-mortar stores and online retailers. The data contain monthly sales and quantity observations at the item–store level from 2017 through 2020. We aggregate these observations to the national item level at a quarterly frequency and calculate total quantity sold and average prices for each item–quarter. This paper presents price indices for notebook computers.

In addition to item-level sales and quantities, the database contains the detailed information on product attributes that we use to implement hedonic methods. They include measures of RAM, storage capacity, screen size, and battery life. We estimate hedonic models using an elastic net approach on a quarter-by-quarter basis, regressing item–quarter price levels or price relatives on observed characteristics to obtain hedonic price estimates. The price relative estimates used the lagged residual from the levels estimates to control for unobserved, time-varying heterogeneity.

III. Empirical Results

Panel (a) of Figure 1 compares the standard UVI with the matched-model arithmetic Laspeyres and Tornqvist. The standard UVI is positive, indicating that the average price of notebook computers increased over the sample period. In stark contrast, the matched-model indices exhibit a consistent rate of deflation, except for the Laspeyres in 2020, when price declines temporarily slowed at the onset of the COVID-19 pandemic. The Tornqvist index lies below the Laspeyres, consistent with

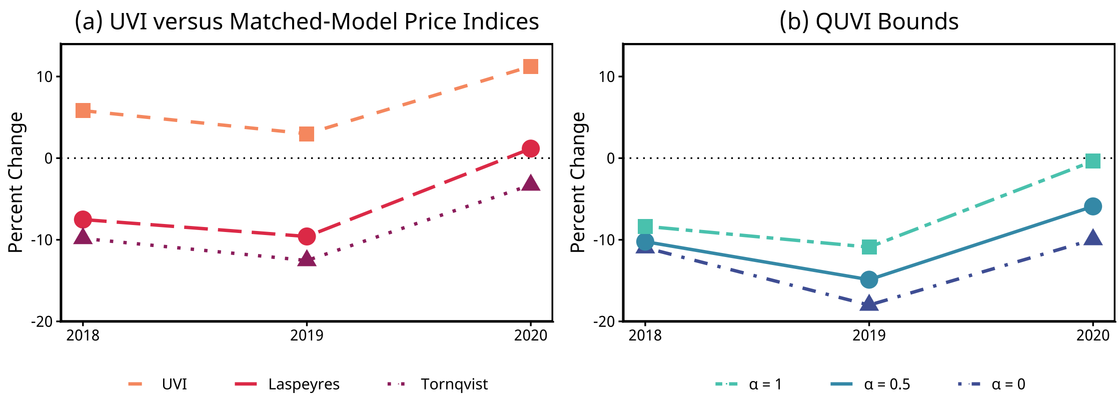

FIGURE 1. COMPARISONS OF UVI AND QUVI: NOTEBOOK COMPUTERS

Note: Panel (a) plots the UVI and traditional price indices and Panel (b) plots the QUVI using different values for the mixing parameter α. Values reported are the annual percent change. These are average quarterly percent changes multiplied by four.

the presence of substitution bias. Taken together, these indices display the conventional ordering, highlighting that the positive growth in the UVI reflects a substantial degree of quality growth. Using the QUVI, we will be able to isolate this quality component of the UVI.

Panel (b) of Figure 1 plots the annual cumulative rate of inflation using the QUVI under alternative values of the mixing parameter α. Consistent with the conceptual framework, the QUVI spans a lower bound given by a hedonic Paasche inclusive of entry and an upper bound given by a hedonic Laspeyres inclusive of exit. The resulting bounds exhibit the expected ordering, with the Laspeyres exceeding the Paasche, and are consistent with a decline in the exact price index over the sample period.

Table 1 compares the decompositions of the standard UVI and the QUVI (percent changes at annual rates). Column 2 reports the decomposition of the standard UVI based on equation (3). The product-mix terms are strongly positive, which generates the large gap between the UVI and the Laspeyres. This reflects a substantial shift toward higher-priced notebook computers over the sample period. The corresponding decomposition of the QUVI is reported in column 5 of Table 1 for the case of $\alpha = 0.5$. In stark contrast to the UVI, the product-mix terms for the QUVI are negative. The decomposition of the QUVI indicates that both the average price for existing models was falling and consumers shifted toward lower-priced notebooks on a quality-adjusted basis. The QUVI with $\alpha = 0.5$ is nearly identical to the full-imputation hedonic Tornqvist reported in column 4. Taken together, the comparison of the decomposition of the standard UVI and the QUVI confirms that the rising average price for notebook computers is a result of quality-upgrading outpacing the change in the quality-adjusted price index.

IV. Conclusion

In this paper, we examine the properties of the unit value index (UVI) and explore new approaches to constructing quality-adjusted unit value indices (QUVIs). We develop an exact decomposition showing that both the UVI and the QUVI can be expressed as the sum of growth in a standard matched-model arithmetic Laspeyres index and a set of product-mix effects.

Using notebook computers as an illustrative case, we find that average prices rose over time primarily because consumers shifted toward higher-quality models. These product-mix effects dominated both declining prices for continuing models and substitution toward goods that were cheaper on a quality-adjusted basis. As a result, movements in the UVI largely reflect quality upgrading rather than inflation. It shows how examining average prices alone overstates inflation and understates

	Laspeyres	UVI	Quality-Adjusted Laspeyres	Quality-Adjusted Tornqvist	QUVI
	(1)	(2)	(3)	(4)	(5)
Within		−6.30			−8.68
Product Mix		8.32			−2.28
Total	−6.62	2.03	−9.06	−10.65	−10.95

TABLE 1—COMPARISON OF DECOMPOSITION OF UVI AND QUVI: NOTEBOOK COMPUTERS

Note: Values equal the annual cumulative percent change from 2017Q1 to 2020Q4. To compute these values, we average the quarterly percent change across all quarters in the sample period and rescale this average by a factor of four. The columns labeled Quality-Adjusted Laspeyres and Quality-Adjusted Tornqvist refers to a matched-model Laspeyres and a full-imputation Tornqvist using predicted price relatives from the EP-TV model, respectively. The column labeled QUVI refers to the case of $\alpha = 0.5$.

improvements in quality, especially for goods subject to rapid technological change.

More broadly, our analysis highlights the rich information embedded in unit value indices when they are interpreted through an appropriate decomposition and quality-adjustment framework. Given the growing availability of detailed product attributes in private-sector point-of-sale data, our results provide practical guidance for firms, data aggregators, analysts, and market participants seeking to distinguish inflation from quality-driven changes in average prices.

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