Supplementary Appendix

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

John Haltiwanger Ron Jarmin R. Benjamin Rodriguez
Matthew D. Shapiro

American Economic Association Papers & Proceedings

January 2026

1 Connections to the Literature

In academic and statistical settings, the growth rate of the average sales price is called the *unit value index* (UVI). UVIs have been widely studied, and both their strengths and limitations are well documented (Balk, 1998; Silver, 2010). For homogeneous products that can be treated as perfect substitutes, the UVI serves as an ideal price index with desirable theoretical properties. For example, it is robust to chain drift and can address outlet substitution bias (Reinsdorf, 1998). Yet, even within narrowly defined product categories, items often vary in quality. In such settings, changes in the average sales price reflect not only price changes but also shifts in product quality and mix, thereby complicating the interpretation of the UVI as a measure of inflation (see, e.g., Fast and Fleck, 2019). To address these limitations, the literature has introduced the concept of a *quality-adjusted unit value index* (QUVI), which accounts for variation in quality across goods by deflating observed prices by quality adjustment factors. A number of studies have developed methods to estimate such factors (von Auer, 2014; de Haan and Krsinich, 2018; Byrne et al., 2017; Aizcorbe and Chen, 2022). We build on this literature by investigating the theoretical and empirical properties of the UVI and QUVI.

First, to illustrate why the UVI differs from traditional matched-model indices, we construct a novel exact decomposition of the UVI into two components: a within-product term and a product mix term. We show that the within term is the matched-model arithmetic Laspeyres index multiplied by scaling factor that is close to one. We thus show that the deviation of the UVI from this benchmark measure of inflation is entirely attributable to product mix effects. These mix effects arise from price dispersion across products, which, in the absence of perfect homogeneity, are typically associated with differences in quality. Changes in average price owing to quality differences arise both from life-cycle dynamics of continuing goods and product entry and exit.

Second, we introduce a new form of quality adjustment in the QUVI based on hedonics. Our approach builds on the existing literature (see, e.g., von Auer, 2014 and de Haan, 2015), which derives conditions under which the measured QUVI yields bounds on the exact price index. We extend this logic by incorporating the methodology of Erickson and Pakes (2011) and Ehrlich et al. (2025), which enables hedonic imputation for both observable and unobservable characteristics. With this form of quality adjustment, the QUVI is bounded between two polar cases: (i) a hedonic Laspeyres index inclusive of product exit; and (ii) a hedonic Paasche index inclusive of product entry. This implementation of the QUVI is consistent with a characteristics-adjusted price index that accounts for product entry and exit.[1]

By combining these elements, our conceptual framework provides a unified lens for interpreting unit value indices in an environment with heterogeneous products and substantial product turnover. Rather than treating movements in average prices as direct measures of inflation, the framework clarifies how such movements reflect a combination of price changes, shifts in product composition, and quality upgrading. The proposed decomposition reveals that the divergence between the UVI and traditional inflation measures is not a statistical artifact, but instead reflects economically meaningful changes in the composition and quality of goods sold.

Extending this decomposition to the QUVI provides a diagnostic tool for distinguishing important channels of inflation. On a quality-adjusted basis, the within-good component isolates average quality-adjusted price changes, while the remaining product-mix terms capture changes in the composition of goods associated with residual dispersion in quality-adjusted prices. Comparing the two decompositions therefore clarifies the extent to which rising average prices are driven by quality upgrading rather than inflation.

Finally, the framework provides a bridge between private-sector practices and current practices in economic measurement. Unit value indices are widely used by firms and data aggregators because they are simple, timely, and consistent with accounting measures of revenue and quantity growth. The framework developed here shows how these same indices can be reinterpreted to separately track inflation, quality growth, and changes in product mix. Moreover, the resulting bounds discipline the interpretation of scanner-based price measures without requiring strong assumptions about consumer demand or complete quality adjustment. In doing so, it offers practical guidance for analysts seeking to extract economically meaningful signals from average prices in modern retail data.

2 Decomposing Unit Value Indices

The average selling price for Ω_t, the basket of goods sold in period t, is:

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

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

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

[1] This bounding approach represents a more modest and achievable objective than the literature that compute a QUVI to serve as a proxy for an exact price index under a linear utility function. As highlighted by Byrne et al. (2017), this more ambitious objective needs to take into account the role of market frictions that yields departures from the strong implications of assuming a linear utility function.

To write the UVI as an exact decomposition of within-item price changes and changes in product-mix, we decompose the level change in average prices, denoted as $\Delta\mathbb{P}_t = \mathbb{P}_t - \mathbb{P}_{t-1}$, as follows:

$$\Delta\mathbb{P}_t = \sum_{k\in\mathbb{C}} w_{kt-1}\Delta p_{kt} + \sum_{k\in\mathbb{C}} \Delta w_{kt} p_{kt-1} + \sum_{k\in\mathbb{C}} \Delta w_{kt}\Delta p_{kt} + \sum_{k\in\mathbb{E}} w_{kt}p_{kt} - \sum_{k\in\mathbb{X}} w_{kt-1}p_{kt-1}$$

where observations are weighted using quantity shares, $w_{kt} = q_{kt}/\sum_{\Omega_t} q_{kt}$, and changes in item-level prices and quantity shares are $\Delta p_{kt} = p_{kt} - p_{kt-1}$ and $\Delta w_{kt} = w_{kt} - w_{kt-1}$, respectively. Moreover, $\mathbb{C}$ denotes the basket of continuing goods, $\mathbb{E}$ denotes the basket of entering goods, and $\mathbb{X}$ denotes the basket of exiting goods.

We rewrite this decomposition in terms of the unit value index:

$$\text{UVI} = 1 + \sum_{k\in\mathbb{C}} w_{kt-1}\left(\frac{\Delta p_{kt}}{P_{t-1}}\right) + \sum_{k\in\mathbb{C}} \Delta w_{kt}\left(\frac{p_{kt}}{P_{t-1}}\right) + \sum_{k\in\mathbb{E}} w_{kt}\left(\frac{p_{kt}}{P_{t-1}}\right) - \sum_{k\in\mathbb{X}} w_{kt-1}\left(\frac{p_{kt-1}}{P_{t-1}}\right)$$

This expression has three terms:

1. The within term, $\sum_{k\in\mathbb{C}} w_{kt-1}\left(\frac{\Delta p_{kt}}{P_{t-1}}\right)$
2. The product mix term for continuing goods, $\sum_{k\in\mathbb{C}} \Delta w_{kt}\left(\frac{p_{kt}}{P_{t-1}}\right)$
3. The product mix term for entering and exiting goods, $\sum_{k\in\mathbb{E}} w_{kt}\left(\frac{p_{kt}}{P_{t-1}}\right) - \sum_{k\in\mathbb{X}} w_{kt-1}\left(\frac{p_{kt-1}}{P_{t-1}}\right)$

We can rewrite the within term to connect it to a traditional matched-model index:

$$\begin{aligned}
\sum_{k\in\mathbb{C}} w_{kt-1}\left(\frac{\Delta p_{kt}}{P_{t-1}}\right) &= \sum_{k\in\mathbb{C}}\left(\frac{p_{kt-1}q_{kt-1}}{\sum_{k\in\Omega_{t-1}} p_{kt-1}q_{kt-1}}\right)\left(\frac{p_{kt}}{p_{kt-1}} - 1\right) \\
&= \left(\frac{\sum_{k\in\mathbb{C}} p_{kt-1}q_{kt-1}}{\sum_{k\in\Omega_{t-1}} p_{kt-1}q_{kt-1}}\right)\sum_{k\in\mathbb{C}}\left(\frac{p_{kt-1}q_{kt-1}}{\sum_{k\in\mathbb{C}} p_{kt-1}q_{kt-1}}\right)\left(\frac{p_{kt}}{p_{kt-1}} - 1\right) \\
&= s^{\mathbb{C}}_{t-1}\sum_{k\in\mathbb{C}} s^{\mathbb{C}}_{kt-1}\left(\frac{p_{kt}}{p_{kt-1}} - 1\right)
\end{aligned}$$

where $s^{\mathbb{C}}_{t-1} = \sum_{k\in\mathbb{C}} p_{kt-1}q_{kt-1}/\sum_{\Omega_{t-1}} p_{kt-1}q_{kt-1}]$ denotes the expenditure share for the basket of continuing goods and $s^{\mathbb{C}}_{kt-1} = p_{kt-1}q_{kt-1}/\sum_{k\in\mathbb{C}} p_{kt-1}q_{kt-1}$ denotes the expenditure share on good k within the basket of continuing goods in period $t-1$. Taken together, the UVI is:

$$\begin{aligned}
\text{UVI} = 1 &+ s^{\mathbb{C}}_{t-1}\sum_{k\in\mathbb{C}} s^{\mathbb{C}}_{kt-1}\left(\frac{p_{kt}}{p_{kt-1}} - 1\right) + \sum_{k\in\mathbb{C}} \Delta w_{kt}\left(\frac{p_{kt}}{P_{t-1}}\right) \\
&+ \sum_{k\in\mathbb{E}} w_{kt}\left(\frac{p_{kt}}{P_{t-1}}\right) - \sum_{k\in\mathbb{X}} w_{kt-1}\left(\frac{p_{kt-1}}{P_{t-1}}\right)
\end{aligned} \tag{3}$$

This set-up can also be applied to the quality-adjusted UVI (QUVI), whose formula is:

$$\begin{aligned}\text{QUVI} &= \frac{\sum_{k\in\Omega_t} p_{kt}q_{kt} / \sum_{k\in\Omega_t} \lambda^{\tau}_{kt}q_{kt}}{\sum_{k\in\Omega_{t-1}} p_{kt-1}q_{kt-1} / \sum_{k\in\Omega_{t-1}} \lambda^{\tau}_{kt-1}q_{kt-1}} \\ &= \frac{\sum_{k\in\Omega_t} w^{\tau}_{kt}(p_{kt}/\lambda^{\tau}_{kt})}{\sum_{k\in\Omega_{t-1}} w^{\tau}_{kt-1}(p_{kt-1}/\lambda^{\tau}_{kt-1})}\end{aligned} \tag{4}$$

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. These weights rely on quality adjustment factors λ^{τ}_{k} defined on a bilateral basis for periods $\tau = \{t-1,\ t\}$. Given the structure of the UVI and QUVI are similar, the steps to decompose the QUVI are the same as for the UVI. Hence, the QUVI is the sum of the same three terms that hold now on a quality-adjusted basis:

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

where $\Delta w^{\tau}_{kt} = w^{\tau}_{kt} - w^{\tau}_{kt-1}$.

3 Bounds for Matched Model Indices

Consider the specification of an adjustment factor for $\tau = \{t-1, t\}$ given by:

$$\overline{\lambda}^{\tau}_{k}(\alpha) = \left(\frac{p_{kt}}{P_t}\right)^{\alpha}\left(\frac{p_{kt-1}}{P_{t-1}}\right)^{1-\alpha} \tag{6}$$

For now we assume away product turnover. The parameter α is a mix parameter that enables using base $t-1$ period or alternatively current t period weights for the price index.

If $\alpha = 1$, the adjustment factor in equation (6) implies the QUVI is equal to the matched-model arithmetic Laspeyres:

$$\begin{aligned}\frac{P_t}{P_{t-1}} &= \frac{\sum_{k\in\Omega} p_{kt}q_{kt} / \sum_{k\in\Omega} p_{kt}q_{kt}}{\sum_{k\in\Omega} p_{kt-1}q_{kt-1} / \sum_{k\in\Omega} p_{kt}q_{kt-1}} \\ &= \frac{\sum_{k\in\Omega} p_{kt}q_{kt-1}}{\sum_{k\in\Omega} p_{kt-1}q_{kt-1}} \\ &= \sum_{k\in\Omega} s_{kt-1}\left[\frac{p_{kt}}{p_{kt-1}}\right]\end{aligned}$$

In the $\alpha = 1$ case, the price dispersion in t is assumed to capture all of the $\lambda_{k\tau}$ dispersion. The resulting price index is the matched-model arithmetic Laspeyres with well-known upper bound properties of the exact price index.

For $\alpha = 0$, this adjustment factor yields the QUVI to be equal to the matched-model arithmetic Paasche:

$$\begin{aligned}\frac{P_t}{P_{t-1}} &= \frac{\sum_{k\in\Omega} p_{kt}q_{kt} / \sum_{k\in\Omega} p_{kt-1}q_{kt}}{\sum_{k\in\Omega} p_{kt-1}q_{kt-1} / \sum_{k\in\Omega} p_{kt-1}q_{kt-1}} \\ &= \frac{\sum_{k\in\Omega} p_{kt}q_{kt}}{\sum_{k\in\Omega} p_{kt-1}q_{kt}} \\ &= \left(\sum_{k\in\Omega} s_{kt}\left[\frac{p_{kt}}{p_{kt-1}}\right]^{-1}\right)^{-1}\end{aligned}$$

4 EP-TV method

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. To implement this procedure, we first estimate a log level hedonic model in the base period by regressing log price levels on a vector of observed product characteristics denoted as Z_k:

$$\ln p_{kt-1} = Z_k' \, \Phi_{t-1} + \eta_{kt-1}$$

Using the log level model, the EP-TV method extracts the estimated residual for $t-1$: $\hat{\eta}_{kt-1}$. Using this lagged residual estimate as a proxy for unobserved characteristics, we include it as an additional control variable in a log difference hedonic model:

$$\Delta \ln p_{kt} = Z_k' \, \beta_t + \kappa_t \hat{\eta}_{kt-1} + \nu_{kt}$$

This approach immediately yields predicted price relatives for continuing goods and exiting goods. We implement the procedures used by Ehrlich et al. (2025) to compute the predicted price relative for entering goods.

5 Quality Adjustment Factors

For extending the bounding approach, we implement the following based on the EP-TV estimates:

$$\begin{aligned}\lambda^{\tau}_{kt-1}(\alpha) &= \left(\widehat{p_{kt}/p_{kt-1}}\right)^{\alpha} \times p_{kt-1} \quad \text{for } k \in \Omega_{t-1} \\ \lambda^{\tau}_{kt}(\alpha) &= \left(\widehat{p_{kt}/p_{kt-1}}\right)^{-(1-\alpha)} \times p_{kt} \quad \text{for } k \in \Omega_t\end{aligned} \tag{7}$$

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 take exponential of the predicted log price relative to generate the quality adjustment factors. There is some approximation error here given the use of estimated values.

This time-varying adjustment approach yields bounds on the rate of inflation. Details for these derivations are as follows. First for the hedonic Paasche with entry:

$$\begin{aligned}\frac{P_t^\tau}{P_{t-1}^\tau} &= \frac{\sum_{k\in\Omega_t} p_{kt}q_{kt} / \sum_{k\in\Omega_{t-1}} p_{kt-1}q_{kt-1}}{\sum_{k\in\Omega_t} \lambda_{kt}^\tau(0)q_{kt} / \sum_{k\in\Omega_{t-1}} \lambda_{kt-1}^\tau(0)q_{kt-1}} \\ &= \frac{\sum_{k\in\Omega_t} p_{kt}q_{kt}}{\sum_{k\in\Omega_t} p_{kt}q_{kt}\left[\widehat{\frac{p_{kt}}{p_{kt-1}}}\right]^{-1}} \\ &= \left(\sum_{k\in\Omega_t} s_{kt}\left[\widehat{\frac{p_{kt}}{p_{kt-1}}}\right]^{-1}\right)^{-1}\end{aligned}$$

where Ω_t includes all items in t ($\Omega_t = \mathbb{C} \cup \mathbb{N}_t$). Now with the hedonic Laspeyres with exit:

$$\begin{aligned}\frac{P_t^\tau}{P_{t-1}^\tau} &= \frac{\sum_{k\in\Omega_t} p_{kt}q_{kt} / \sum_{k\in\Omega_{t-1}} p_{kt-1}q_{kt-1}}{\sum_{k\in\Omega_t} \lambda_{kt}^\tau(1)q_{kt} / \sum_{k\in\Omega_{t-1}} \lambda_{kt-1}^\tau(1)q_{kt-1}} \\ &= \frac{\sum_{k\in\Omega_t} p_{kt}q_{kt} / \sum_{k\in\Omega_{t-1}} p_{kt-1}q_{kt-1}}{\sum_{k\in\Omega_t} p_{kt}q_{kt} / \sum_{k\in\Omega_{t-1}} \left[\widehat{p_{kt}/p_{kt-1}}\right] p_{kt-1}q_{kt-1}} \\ &= \frac{\sum_{k\in\Omega_{t-1}} \left[\widehat{\frac{p_{kt}}{p_{kt-1}}}\right] p_{kt-1}q_{kt-1}}{\sum_{k\in\Omega_{t-1}} p_{kt-1}q_{kt-1}} \\ &= \sum_{k\in\Omega_{t-1}} s_{kt-1}\left[\widehat{\frac{p_{kt}}{p_{kt-1}}}\right]\end{aligned}$$

where Ω_{t-1} includes all items in $t-1$ ($\Omega_{t-1} = \mathbb{C}_t \cup \mathbb{X}_t$).

6 Use of Average Sales Prices by Commercial Sector

Walmart regularly reports trends in its average sales price—referred to as the AUR (average unit retail); see https://corporate.walmart.com/content/dam/corporate/documents/newsroom/2025/05/15/walmart-releases-q1-fy26-earnings/q1-fy26-earnings-call-transcript.pdf. Amazon similarly discusses ASP (average sales price) see https://s2.q4cdn.com/299287126/files/doc_financials/2023/q4/Amazon-Q4_2023_Transcript.pdf. Circana, a leading provider of retail transaction data (and the source of our data), regularly reports on average price patterns; see https://www.circana.com/post/us-office-supplies-sales-revenue-declined-2-in-2022. CIRP conducts equity securities research to the investment community and tracks the average sales price for numerous firms including Apple (see, https://cirpapple.substack.com/p/latest-iphone-average-selling-price). It should be emphasized that retailers and industry analysts are well aware that the product mix impacts the average sales price even in narrowly defined product groups.

Even so, the average sales price is often discussed as providing insights about inflation (see https://cbgmanagementcoaching.co.uk/wp-content/uploads/2024/10/Nielsen-Guide-to-2025-Mid-Year-Consumer-Outlook-Full-Report_90de1a.pdf).

References

Aizcorbe, A. M. and Chen, J. (2022). *Outlet Substitution Bias Estimates for Ride Sharing and Taxi Rides in New York City*. US Department of Commerce, Bureau of Economic Analysis.

Balk, B. M. (1998). *On the Use of Unit Value Indices as Consumer Price Subindices*. Paper presented at the fourth meeting of the Ottawa Group.

Byrne, D. M., Kovak, B. K., and Michaels, R. (2017). Quality-Adjusted Price Measurement: A New Approach with Evidence from Semiconductors. *Review of Economics and Statistics*, 99(2):330–342.

de Haan, J. (2015). *A Framework for Large Scale Use of Scanner Data in the Dutch CPI*. Report from Ottawa Group 14th meeting, International Working Group on Price Indices, Tokyo (Japan).

de Haan, J. and Krsinich, F. (2018). Time Dummy Hedonic and Quality-Adjusted Unit Value Indexes: Do They Really Differ? *Review of Income and Wealth*, 64(4):757–776.

Ehrlich, G., Haltiwanger, J. C., Jarmin, R. S., Johnson, D., Olivares, E., Pardue, L. W., Shapiro, M. D., Zhao, L., et al. (2025). Quality Adjustment at Scale: Hedonic vs. Exact Demand-Based Price Indices. Technical report, National Bureau of Economic Research (revised in 2025).

Erickson, T. and Pakes, A. (2011). An Experimental Component Index for the CPI: From Annual Computer Data to Monthly Data on Other Goods. *American Economic Review*, 101(5):1707–1738.

Fast, D. A. and Fleck, S. E. (2019). Unit Values for Import and Export Price Indexes: a Proof of Concept. In *Big Data for 21st Century Economic Statistics*. University of Chicago Press.

Reinsdorf, M. B. (1998). Formula Bias and Within-Stratum Substitution Bias in the US CPI. *Review of Economics and Statistics*, 80(2):175–187.

Silver, M. (2010). The Wrongs and Rights of Unit Value Indices. *Review of Income and Wealth*, 56:S206–S223.

von Auer, L. (2014). The Generalized Unit Value Index Family. *Review of Income and Wealth*, 60(4):843–861.