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

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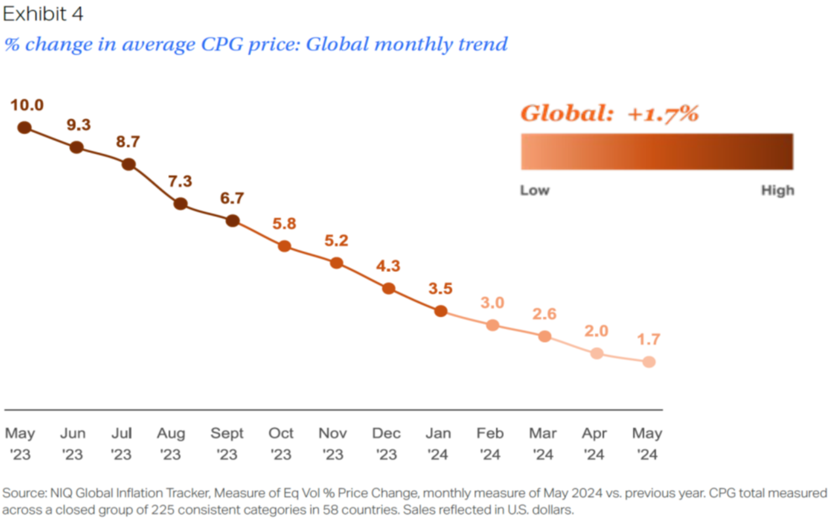
Average Sales Prices Increasingly Used by Retailers and Market Analysts



Source: NielsenIQ Mid-Year Outlook for 2025

This Paper

- In the age of Big Data, retailers and analysts increasingly use average sales price indices (i.e., unit value indices, UVIs) to track market activity
- UVIs confounds inflation with changes in product mix
- We develop an exact decomposition of UVIs into:
  1. A within component $\approx$ the arithmetic Laspeyres index
  2. A product mix term
- Product mix reflects consumer substitution, especially arising from quality change of entering and exiting goods
- QUVI: Quality-Adjusted Unit Value Index
  1. Construct QUVI using hedonics
  2. Show mix component driven by quality change

Data and Empirical Specification

- Notebook computers:
  - ⇒ POS data from Circana at item level
  - ⇒ National
  - ⇒ Quarterly, 2017-2020
- Item-level prices, quantities and detailed attributes of products
  1. Hedonics using Erickson and Pakes (2011) as implemented by Ehrlich et al. (2025)
  2. Attributes include battery life, disk space, RAM, screen size, etc.
  3. Full-imputation of entering, exiting, and continuing goods

Unit Value Indices (UVIs) - Definition

– The average selling price for a basket of goods Ω in period t is:

$$\mathbb{P}_t = \frac{\sum_{k \in \Omega_t} p_{kt} q_{kt}}{\sum_{k \in \Omega_t} q_{kt}}$$

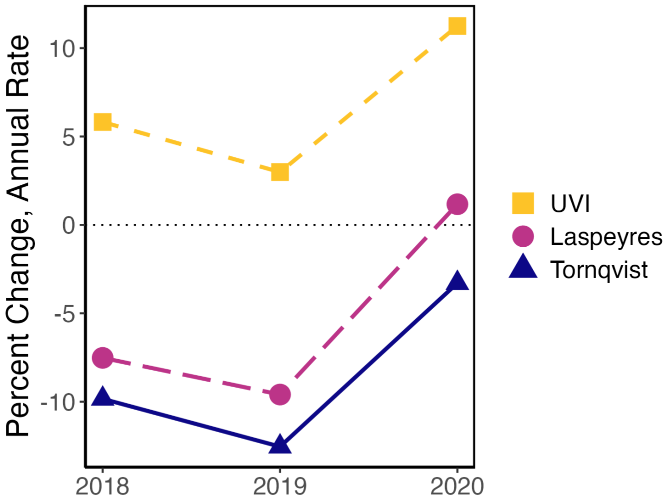
– UVI is defined as the ratio of average selling prices across periods:

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

– When a basket of goods are homogeneous (e.g. UPCs), the UVI is an exact price index, but it is commonly used in other contexts:

1. ...by retailers and market analysts as indicators of price trends
2. ...with POS data to indicate inflation for specific product classes

UVI Overstates Inflation: Notebook Computers



Decomposing the UVI

$$\frac{\mathbb{P}_t}{\mathbb{P}_{t-1}} = 1 + \underbrace{s^{\mathbb{C}}_{t-1} \overbrace{\sum_{k \in \mathbb{C}} s^{c}_{kt-1} \left(\frac{p_{kt}}{p_{kt-1}} - 1 \right)}^{\text{Arithmetic Matched-Model Laspeyres}}}_{\text{Within}}$$

$$+ \underbrace{\sum_{k \in \mathbb{C}} \Delta w_{kt} \left(\frac{p_{kt}}{\mathbb{P}_{t-1}} \right) + \sum_{k \in \mathbb{E}} w_{kt} \left(\frac{p_{kt}}{\mathbb{P}_{t-1}} \right) - \sum_{k \in \mathbb{X}} w_{kt-1} \left(\frac{p_{kt-1}}{\mathbb{P}_{t-1}} \right)}_{\text{Product Mix}}$$

1. s^{c}_{kt-1} is the expenditure share of good k out the basket of common goods in period $t-1$
2. $s^{\mathbb{C}}_{t-1}$ is the expenditure share of common goods in period $t-1$
3. w_{kt} is the quantity share weight of good k in period t
4. $\mathbb{C}_t$, $\mathbb{E}_t$, and $\mathbb{X}_t$ denote the common goods between $t-1$ and t, and goods entering and exiting in t

Decomposing the UVI: Inflation + Product Mix

Notebook Computers

Percent Change (Annual Rate)

	Laspeyres (1)	UVI (2)
Within		−6.30
Product Mix		8.32
Total	−6.62	2.03

– The entire gap between the UVI and the matched-model Laspeyres is driven by product mix: within-good prices are falling, but shifts toward higher-priced models raise the average price.

Quality-Adjusted UVIs (QUVIs) - Definition

- QUVIs incorporate adjustment factors to rescale quantity shares and price levels to calculate "quality-adjusted" average prices:

$$\text{QUVI} = P_t^\tau / P_{t-1}^\tau = \frac{\sum_{k\in\Omega_t} p_{kt} q_{kt} / \sum_{k\in\Omega_{t-1}} p_{kt-1} q_{kt-1}}{\sum_{k\in\Omega_t} \lambda_{kt}^\tau q_{kt} / \sum_{k\in\Omega_{t-1}} \lambda_{kt-1}^\tau q_{kt-1}}$$

  where λ_{kt}^τ is the adjustment factor of good k in period t, τ refers to the pairwise periods {t-1,t}, $P_t^\tau = \frac{\sum_{k\in\Omega_t} p_{kt} q_{kt}}{\sum_{k\in\Omega_t} \lambda_{kt}^\tau q_{kt}}$, and $P_{t-1}^\tau = \frac{\sum_{k\in\Omega_{t-1}} p_{kt-1} q_{kt-1}}{\sum_{k\in\Omega_{t-1}} \lambda_{kt-1}^\tau q_{kt-1}}$

- When tracking the price of bottles of water that vary in size, a simple adjustment factor would rescale quantities by the number of ounces of water in each bottle
  $\Rightarrow$ Determining factors for notebook computers is not mechanical

- We estimate these adjustment factors using a hedonic imputation approach that yields upper and lower bounds on the quality-adjusted price index in the presence of product entry and exit.

A Bounding Approach: Pairwise Time-Invariant

- *Basic adjustment* generalizes work by von Auer (2014) and de Haan (2015) assuming pairwise time-invariant adjustment-factors:

$$\lambda_{kt}^{\tau} = \lambda_{kt-1}^{\tau}$$

- Use observed price dispersion over adjacent periods to estimate:

$$\overline{\lambda}_{k}^{\tau}(\alpha) = p_{kt}^{\alpha} p_{kt-1}^{1-\alpha}$$

  where mixing parameter α determines weight put on period $t-1$ versus t

- In the absence of product turnover, using the basic approach yields Konus bounds:

Mixing Parameter	Adjustment Factors	QUVI Equivalence
$\alpha = 0$	$\overline{\lambda}_{k}^{\tau}(0) = p_{kt-1}$	Matched-Model Paasche
$\alpha = 1$	$\overline{\lambda}_{k}^{\tau}(1) = p_{kt}$	Matched-Model Laspeyres

Full Imputation EP-TV Hedonics

– Two stage method from Erickson and Pakes (2011) that accounts for both observable and unobservable characteristics

1. First stage:
$$\ln p_{kt-1} = Z_k' \, \Phi_{t-1} + \eta_{kt-1}$$
Extract estimated residual for $t-1$: $\hat{\eta}_{kt-1}$ as proxy for unobserved characteristics.
2. Second stage:
$$\Delta \ln p_{kt} = Z_k' \, \beta_t + \kappa_t \hat{\eta}_{kt-1} + \nu_{kt}$$
Use second stage to estimate predicted price relatives for continuing, exiting, and entering goods (Ehrlich et al., 2025)

Bounds Inclusive of Product Entry and Exit: Time-Varying Adjustment

– Use Erickson and Pakes (2011) **full-imputation** (for continuing, entering and exiting goods):

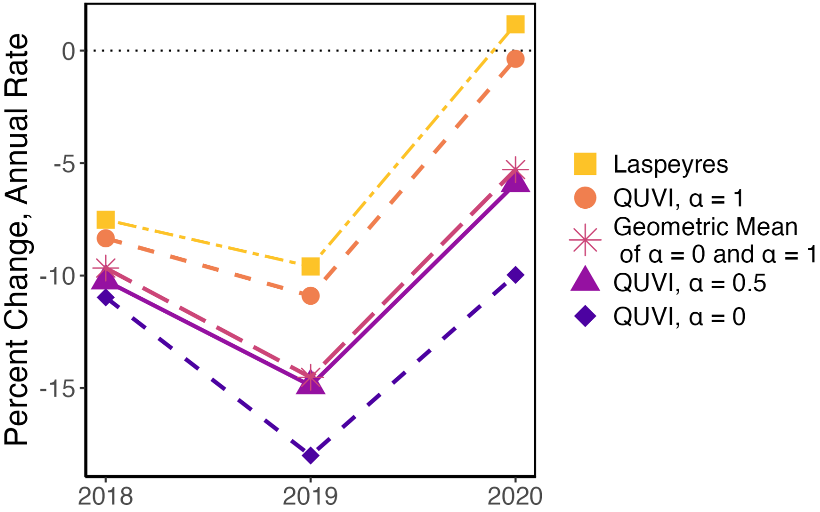
$$\lambda^{\tau}_{kt-1}(\alpha) = \left(\widehat{p_{kt}/p_{kt-1}}\right)^{\alpha} \times p_{kt-1}$$
$$\lambda^{\tau}_{kt}(\alpha) = \left(\widehat{p_{kt}/p_{kt-1}}\right)^{-(1-\alpha)} \times p_{kt}$$

where $\widehat{p_{kt}/p_{kt-1}}$ is the predicted price relative from first difference hedonic model estimated for the difference between $t-1$ and t

– Under values of α, QUVI equivalent to **full-imputation** hedonic bounds:

Mixing Parameter	QUVI Equivalence
$\alpha = 0$	Hedonic Paasche with Entry
$\alpha = 1$	Hedonic Laspeyres with Exit
$\alpha = 0.5$	Hedonic Davies with Entry and Exit

QUVI Hedonic Bound Equivalences: Notebook Computers



Decomposing the QUVI:

$$\text{QUVI} = 1 + \underbrace{s^{\mathbb{C}}_{t-1} \overbrace{\sum_{k \in \mathbb{C}} s^{c}_{kt-1} \left(\frac{p_{kt}/\lambda^{\tau}_{kt}}{p_{kt-1}/\lambda^{\tau}_{kt-1}} - 1 \right)}^{\text{Quality-Adjusted Matched-Model Laspeyres}}}_{\text{Within}}$$

$$+ \underbrace{\sum_{k \in \mathbb{C}_t} \Delta\omega^{\tau}_{k} \left(\frac{p_{kt}/\lambda^{\tau}_{kt}}{P^{\tau}_{t-1}} \right) + \sum_{k \in \mathbb{E}_t} \omega^{\tau}_{kt} \left(\frac{p_{kt}/\lambda^{\tau}_{kt}}{P^{\tau}_{t-1}} \right) - \sum_{k \in \mathbb{X}_t} \omega^{\tau}_{kt-1} \left(\frac{p_{kt-1}/\lambda^{\tau}_{kt-1}}{P^{\tau}_{t-1}} \right)}_{\text{Product Mix}}$$

where ω^{τ}_{kt} is the quality-adjusted quantity share of good k in period t:

$$\omega^{\tau}_{kt} = \frac{\lambda^{\tau}_{kt} q_{kt}}{\sum_{k \in \Omega_t} \lambda^{\tau}_{kt} q_{kt}} \quad \text{and} \quad P^{\tau}_{t-1} = \frac{\sum_{k \in \Omega_{t-1}} p_{kt-1} q_{kt-1}}{\sum_{k \in \Omega_{t-1}} \lambda^{\tau}_{kt-1} q_{kt-1}}$$

Decompositions on a Quality-Adjusted Basis

Notebook Computers - Percent Change (Annual Rate)

	Laspeyres	UVI	Quality-Adjusted Laspeyres	Quality-Adjusted Tornqvist	QUVI $\alpha = 0.5$
	(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

- QUVI is negative and closely aligned with other indices after adjusting for quality
- UVI's positive product-mix effects reverse sign with the QUVI indicating consumers shifted to lower quality-adjusted prices

Taking Stock

- Framework extends the use of UVIs:
  1. Rising average prices of notebook computers surpasses matched-model indices
  2. The divergence is driven by consumers switching toward higher-priced models
  3. . . . reflecting quality growth outpacing quality-adjusted price deflation

- Additional considerations to advance methods of quality adjustment:
  1. Chain drift:
     - We have avoided addressing chain drift given focus on quarterly rates (and simple summary statistics of such rates).
     - Even if we had considered chained indices, our use of national, quarterly data with full imputation hedonics mitigates chain drift (Ehrlich et al., 2025).
     - Addressing chain drift in disaggregated settings important (e.g., monthly frequency).
  2. Quality-adjusted price dispersion:
     - Bounding approach holds under general assumptions
     - Use of QUVI as proxy for exact price index requires factors span price dispersion
     - In practice, accounting for market frictions (e.g., Byrne et al., 2017) important to relax strong assumptions regarding the QUVI as an exact price index

Thank you!

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