Note to Organizers: This submission includes an abstract and a slide deck. The results have just been cleared by Census Disclosure Review Board and we have been able to produce a slide deck (in process) based on those results and will have a draft paper in the near future (easily by July).

Change in Average Prices: Inflation, Quality Change or Market Frictions?

By
John Haltiwanger[a], Ron Jarmin[b], R. Benjamin Rodriguez[a], and Matthew D. Shapiro[c]

Digitized item-level transactions data allows for the calculation of the average sale price for the universe of items within a product group. Such measures, which are formally referred to as unit value indices (UVI) by academics and statisticians, are often used by retail companies and information aggregators to monitor market changes across a wide variety of product groups. Items classified within the same product groups often differ in quality, and in this case, the change in the average sales price reflects a combination of changing prices, quality, and product mix. Hence, the unit value indices reflect both general inflation and many other factors. To distinguish changes in unit value arising from inflation and other factors, we develop a decomposition of the change in average prices into *within* and *between* terms for continuing goods and a *net-entry* term for entering and exiting goods. Our decomposition shows that the within term for continuing goods is the Laspeyres price index (weighted by the share of continuing goods) while the between and net entry terms reflect changes in product mix that potentially reflect interactions of differences in prices, quantities and quality/product appeal factors.

To interpret the product mix components of the decomposition, we extend our methodology to incorporate the quality adjusted unit value index (QUVI). The price index literature has demonstrated that the quality adjusted unit value index has desirable properties, conditional of course on the methodology to quantify quality adjusted prices for items. The quality adjusted index under some preference assumptions is an exact price index when quality adjustment converts heterogeneous items into a basket of homogeneous goods. In the absence of market frictions, an implication under these assumptions is that residual quality adjusted price dispersion is zero within a product group. We show that the contribution of market frictions can be inferred from the presence of residual quality adjusted price dispersion. In turn, we develop a quality adjusted unit value index that is robust to the presence of market frictions.

We use the Circana consumer tech item-level data to decompose UVIs and QUVIs with and without considering residual quality adjusted price dispersion. We use alternative methods for computing the quality adjusted prices including hedonic methods to incorporate time varying quality adjustment. For the quality adjusted unit value index with or without market frictions, we provide evidence on how our decomposition provides novel insights into measuring the rate of inflation. We also compare empirically the quality adjusted unit value index in the presence of market frictions with the recently developed CES Unified Price Index (CUPI), which is a quality adjusted price index that uses an assumption of imperfect substitutability to account for residual quality adjusted price dispersion.

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

March 2025

This presentation uses data from Circana (formerly the NPD Group) housed at the U.S. Census Bureau. All results using the Circana data have been reviewed to ensure that no confidential information has been disclosed (CBDRB-FY25-0173). Opinions and conclusions expressed are those of the authors and do not represent the view of the U.S. Census Bureau.

Motivation

- The change in average sales prices (or unit value indices, UVIs) at the product group level have current applications in both private and public sectors:
  1. Tracking industry trends in the commercial sector
  2. Constructing import/export prices
  3. Measuring the rate of inflation
- The UVI is an ideal measure of inflation when items are homogeneous but will only weakly pass the constant price test when goods vary in quality:

$$\text{UVI}(\vec{p}, \vec{p}, \vec{q}_{t-1}, \vec{q}_t) = 1 \iff \vec{q}_{t-1} = \vec{q}_t$$

  1. Helpful to track the inflation in price of a dozen chicken eggs
  2. Less informative when measuring inflation for new computers
- Focus of this project:

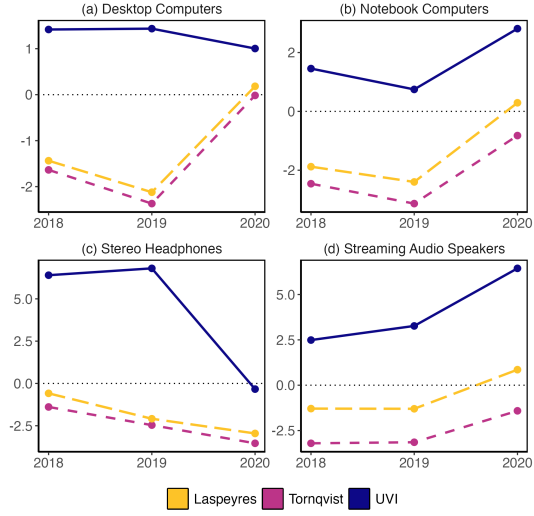
  Produce quality adjusted UVIs that accurately measure the rate of inflation for both new computers and chicken eggs

Using the UVI versus Matched Model Indices

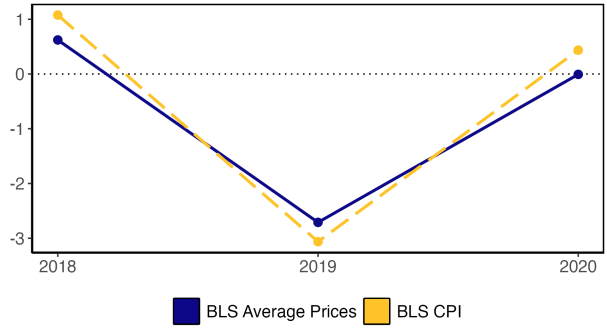
- The UVI formula equals total sales growth over total quantity growth:

$$\frac{\sum_{k\in\Omega_t} p_{kt}q_{kt} / \sum_{k\in\Omega_{t-1}} p_{kt-1}q_{kt-1}}{\sum_{k\in\Omega_t} q_{kt} / \sum_{k\in\Omega_{t-1}} q_{kt-1}}$$

- The UVI is substantially higher compared to matched model indices:
  - $\Rightarrow$ Changes in product mix towards higher priced items within these product groups
  - $\Rightarrow$ Is this a result of products varying in quality? We think so!



Compare that to Eggs. . .



- Consider Average Prices equivalent to UVI and CPI equivalent to Laspeyres
- Unlike consumer electronics, UVI suffers less from product mix effects as eggs differ less in quality
  - ◇ Important to acknowledge series differ slightly in product definition

Incorporating Quality Adjustment

– To isolate true measure of inflation in the UVI, we use the quality adjusted UVI (QUVI) where growth in total quality λ normalizes total sales growth:

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

– While the QUVI is not a new concept in index theory, we provide new guidance on defining quality adjustment factors that are consistent with theory and data:

⇒ Standard theoretical foundation of the QUVI relies on assuming quality adjustment factors makes goods perfect substitutes (implying a law of one price)

⇒ Do raw prices equalize, quality adjusted prices equalize, or does something more general need to hold?

This Paper

- We extend the empirical literature on UVIs:
  1. Use accounting decompositions to understand deviations in UVIs from matched model indices
  2. Use quality adjustment factors that account for rich time varying changes in quality/product appeal
  3. Motivated by the presence of dispersion in quality adjusted prices, we develop a QUVI that takes into account market frictions when calculating product quality

- Preview of Findings:
  1. Time varying adjustment captures inflation unaccounted for using prior methods
  2. Accounting for residual price dispersion additionally lowers the QUVI on average

Literature

- **Using UVIs to track inflation and quality growth.**
  Balk (1995), Bils and Klenow (2001), Bils (2009), De Haan and Krsinich (2018)

  New: (1) Decompose indices to understand sources of growth, (2) Allow for time varying quality adjustment within QUVI framework

- **Accounting for quality and market frictions to measure inflation.**
  Baye (1985), Byrne et al. (2017), Redding and Weinstein (2020), Errico and Lashkari (2024)

  New: Extends quality adjustment to account for price dispersion coming from quality differences and market frictions

- **Using POS data to produce more accurate measures of inflation.**
  Cafarella et al. (2023), Ehrlich et al. (2023)

  New: Produces novel measures of inflation using scanner data

Measurement Framework

Part I - Decomposing the UVI

Interpreting the UVI

- Applying the accounting decomposition from Foster et al. (2001) (FHK) to the UVI shows it has a direct connection to a Laspeyres index:

$$\text{UVI} = 1 + S^c_{t-1} \sum_{k \in C} s^c_{kt-1} \left(\frac{p_{kt}}{p_{kt-1}} - 1 \right) + \sum_{k \in C} \Delta w_k \left(\frac{p_{kt}}{P_{t-1}} \right) + \sum_{k \in N} w_{kt} \left(\frac{p_{kt}}{P_{t-1}} \right) - \sum_{k \in X} w_{kt-1} \left(\frac{p_{kt-1}}{P_{t-1}} \right)$$

  where $\{s, S\}$ denote expenditure shares, w denotes quantity shares, and basket of goods is stratified across entering (N), exiting (X), and continuing (C) goods

- The UVI is the exact price index under the perfect substitutes aggregator:

$$Q_t = \sum_{k \in \Omega_t} q_{kt}$$

  where the law of one price must hold: $p_{kt} = P_t \ \forall \ k \in \Omega_t$

  $\Rightarrow$ If the law of one price holds, then the UVI should equal the Laspeyres

Applying the FHK Decomposition to the UVI

	Laspeyres	Within	Continuers	Net-Entry	UVI
	(1)	(2)	(3)	(4)	(5)
Desktop Computers	−1.59	−1.51	−7.57	10.84	1.77
Notebook Computers	−1.65	−1.57	−13.52	15.60	0.51
Stereo Headphones	−1.49	−1.49	3.06	4.30	5.87
Streaming Audio Speakers	−1.47	−1.47	−0.40	3.33	1.46

- Average price changes (i.e. the Within term) closely tracks the Laspeyres index
- Additional terms indicate change in average prices are elevated by consumers buying more expensive and likely new higher quality items

Measurement Framework

Part II - Introducing Time Varying Quality Adjustment

The Formula for the QUVI

- The main formula for the QUVI simplifies to the relative change in average quality adjusted prices:

$$\text{QUVI} = \frac{\sum_{k \in \Omega_t} \omega_{kt} \left[p_{kt} / \lambda_{kt} \right]}{\sum_{k \in \Omega_{t-1}} \omega_{kt-1} \left[p_{kt-1} / \lambda_{kt-1} \right]}$$

  where ω_{kt} is the quality adjusted quantity weight for a given good k:

$$\omega_{kt} = \lambda_{kt} q_{kt} / \sum_{k \in \Omega_t} \lambda_{kt} q_{kt}$$

- Prior work on measuring quality terms λ_{kt} that informs our approach:
  1. Byrne et al. (2017) (BKM) accounts for market frictions that biases quality adjustment factors based on price levels
  2. De Haan and Krsinich (2018) apply hedonic methods to isolate quality adjustment factors across goods using product characteristics

Overview of Byrne et al. (2017)

- Posit that market frictions impede customers from substituting to new lower priced items but decay over a product's life-cycle
- These market frictions distort prices early on in a good's life-cycle
- Recommends using long-run prices when market frictions do not distort price relatives to adjust for differences in product quality:

$$\frac{\lambda_k}{\lambda_b} = \frac{p_{kT(k)}}{p_{bT(b)}}$$

- Comments:
  1. Unclear if QUVI remains ideal index in measurement framework given market frictions appear in the assumed quality adjusted law of one price
  2. Relying on long-run price relatives delays calculating the QUVI with necessary data

Overview of De Haan and Krsinich (2018)

- Isolates quality differences across goods using information from time-dummy hedonic model:

$$\ln p_{k\tau} = \gamma + \rho_t + F(X_k) + u_{k\tau} \text{ for } \tau \in \{t-1,\ t\}$$

- Quality adjustment factors isolates price variation based on characteristics X_k:

$$\lambda_{kt-1} = \exp(\hat{u}_{kt-1})\ p_{kt-1} \text{ and } \lambda_{kt} = \exp(\hat{u}_{kt} - \hat{\rho}_t)\ p_{kt}$$

  which encodes the estimated rate of inflation $\exp(\hat{\rho}_t)$ into QUVI
- However, the time dummy method does not take into account unobservable product characteristics and imposes constant coefficient on adjacent periods

Outline of Time Varying Quality Adjustment

- First, we utilize information from Erickson and Pakes (2011) hedonic model:

$$\Delta \ln p_k = F(X_k, \hat{\epsilon}_{kt-1}) + e_k$$

  where $\{X_k,\ \hat{\epsilon}_{kt-1}\}$ are product characteristics used as explanatory variables

- We assume quality adjusted log price changes approx. equal hedonic prediction:

$$\Delta \ln p_k / \lambda_k \approx \Delta \widehat{\ln p_k} \Rightarrow \Delta \ln \lambda_k \approx \hat{e}_k$$

- Second, we measure quality that is common across periods:

$$\bar{\lambda}_k \propto p_{kt-1}^{1-\alpha} p_{kt}^{\alpha}$$

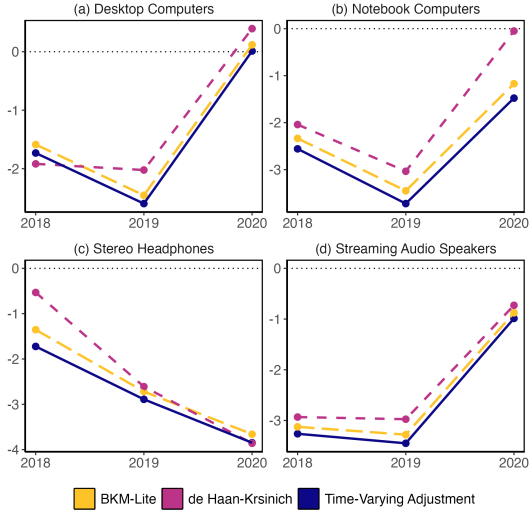
  where timing parameter $\alpha \in [0, 1]$ determines weight put on period $t-1$ or t

- Third, we combine average quality level and predicted changes in quality:

$$\lambda_{kt-1} \approx \ \exp(-\alpha \hat{e}_k) \times \bar{\lambda}_k \text{ and } \lambda_{kt} \approx \exp([1-\alpha]\hat{e}_k) \times \bar{\lambda}_k$$

Comparison of Alternative Approaches

- We compare our definition of quality to methods in De Haan and Krsinich (2018) and Byrne et al. (2017)
  - ⇒ Previous work assumes that quality does not vary between periods
- Time varying quality adjustment persistently captures the greatest amount of quality growth



Is our Implementation of the QUVI Consistent with First Principles?

- The QUVI is the exact price index under the perfect substitutes aggregator with quality differences λ_{kt}:

$$Q_t = \sum_{k \in \Omega_{kt}} \lambda_{kt} q_{kt}$$

  where the quality adjusted law of one price must hold:

$$P_t = p_{kt} / \lambda_{kt} \ \forall \ k \in \Omega_t$$

- If the quality adjusted law of one price holds, then the product mix terms in the FHK decomposition of the QUVI again cancel out and leaving only a quality adjusted Laspeyres

FHK Decomposition of the QUVI

Decomposing the QUVI

	QA Laspeyres	Within	Continuers	Net-Entry	QUVI
	(1)	(2)	(3)	(4)	(5)
Desktop Computers	−1.96	−1.86	−10.27	10.22	−1.90
Notebook Computers	−2.26	−2.17	−16.44	15.87	−2.74
Stereo Headphones	−2.49	−2.49	−4.60	3.66	−3.43
Streaming Audio Speakers	−1.80	−1.79	−4.98	3.40	−3.37

- Average price changes (within term) closely tracks the quality adjusted Laspeyres
- Additional terms indicate change in average prices are elevated by consumers buying more expensive and likely new higher quality items

Persistence of Residual Price Dispersion

	Levels (logs)				Relatives (logs)	
	Raw	de Haan-Krsinich	BKM-Lite	Time Varying Adjustment	Raw	Erickson-Pakes
	(1)	(2)	(3)	(4)	(5)	(6)
Desktop Computers	1.113	0.973	0.003	0.002	0.010	0.007
Notebook Computers	0.778	0.697	0.004	0.003	0.017	0.009
Stereo Headphones	1.446	0.928	0.013	0.004	0.055	0.017
Streaming Audio Speakers	1.180	0.968	0.015	0.012	0.058	0.046

- To test for residual price dispersion in our data, we look at the average quarterly variance in prices across a variety of methods to adjust for quality
- Because of quality adjusted law of one price does not holds then measure of quality is biased as a result

Measurement Framework

Part III - Accounting for Residual Price Dispersion

Accounting for Residual Price Dispersion

- Starting with the quality adjusted perfect substitutes preference, we add an additional constraint to consumer's optimization problem which limits deviations from an ideal basket $\{q^*_{kt}\}_{k \in \Omega_t}$:

$$\lambda_{kt} \left(q_{kt} - q^*_{kt} \right) \leq Q_k$$

  where the quality adjusted law of one price holds when $q_{kt} = q^*_{kt} \ \forall \ k \in \Omega_t$
- Adding this constraint implies a frictional law of one price must hold:

$$P_t = z_{kt} p_{kt} / \lambda_{kt} \ \forall \ k \in \Omega_t$$

  where a wedge z_{kt} represents residual price dispersion unexplained by quality λ_{kt}
- Given wedges z_{kt} cancel out on average around average price P_t, wedges will not appear in the exact price index but will be crucial for measuring level quality differences across goods

An Expression for the Exact Price Index

- Again, we combine the FHK decomposition and the frictional law of one price to reinterpret the exact price index
- When the frictional law of one price holds, the exact price index incorporates the quality adjusted Laspeyres plus additional product mix terms:

$$\frac{P_t}{P_{t-1}} = \left(\frac{S_t^c}{S_{t-1}^c}\right)^{-1} \left(\sum_{k \in C} s_{kt}^c \left[\frac{\omega_{kt}}{\omega_{kt-1}}\right]^{-1}\right)^{-1} \left(\sum_{k \in C} s_{kt-1}^c \left[\frac{p_{kt}/\lambda_{kt}}{p_{kt-1}/\lambda_{kt-1}}\right]\right)$$

which accounts for three changes relevant for measuring inflation:

1. Average quality adjusted price changes
2. Average change in quality adjusted quantity weights
3. Overall representativeness of continuing goods

An Identification Problem Arises

- Using the frictional law of one price, we can invert average quality as a function of prices and wedges:

$$\bar{\lambda}_k \propto \left[z_{kt-1} p_{kt-1}\right]^{1-\alpha} \times \left[z_{kt} p_{kt}\right]^{\alpha}$$

- However, wedges are unobserved meaning we have an identification issues
- To implement our measurement of quality:
  1. We assume price relative equalize over periods:

$$\frac{P_t}{P_{t-1}} = \left(\frac{z_{kt}}{z_{kt-1}}\right)\left(\frac{p_{kt}/\lambda_{kt}}{p_{kt-1}/\lambda_{kt-1}}\right)$$

  2. Measure residual price dispersion over a product's life-cycle
  3. Normalize initial wedge $z_{k0(k)}$ or terminal wedge $z_{kT(k)}$ to one
- Hands are tied to having only one measure of residual price dispersion at a time, but we can implement in the extreme cases where $\alpha \in \{0,\ 1\}$

Quality and the Timing Parameter's Value

– To calculate the frictional QUVI, we use the following values to define quality:

$$\lambda_{kt-1} = \begin{cases} z_{kt-1} p_{kt-1} & \text{when } \alpha = 0 \\ \exp(-\hat{e}_k) \times (z_{kt} p_{kt}) & \text{when } \alpha = 1 \end{cases}$$

$$\lambda_{kt} = \begin{cases} \exp(\hat{e}_k) \times (z_{kt-1} p_{kt-1}) & \text{when } \alpha = 0 \\ z_{kt} p_{kt} & \text{when } \alpha = 1 \end{cases}$$

– Price levels are imputed for entering and exiting goods using same hedonic model

– Wedges evolve while goods have positive sales and held constant during stockouts

– These two extreme cases for the frictional QUVI provide bounds on the rate of inflation with respect to the potential value of timing parameter $\alpha \in [0,\ 1]$

What Effect does Residual Price Dispersion have on the QUVI?

- With our set-up, an increase in residual price dispersion (z) for a good k lowers the QUVI by its change in quality adjusted quantity weights:

$$\frac{\partial \ln \text{FQUVI} \mid_{\alpha=1}}{\partial \ln z_{kt} \mid_{\alpha=1}} = -\Delta\omega_k$$

  where the effect of $z_{kt-1} \mid_{\alpha=0}$ on QUVI $\mid_{\alpha=0}$ is symmetric
- Assuming on average quality adjusted quantity shares increase over a good's life-cycle then we should expect the QUVI to fall as a result of low quality adjusted prices
- For example, quality adjusted prices can fall as a result of the following:
  1. Merchandise sales
  2. Discount stores
  3. Coupons or rebates

Empirical Results

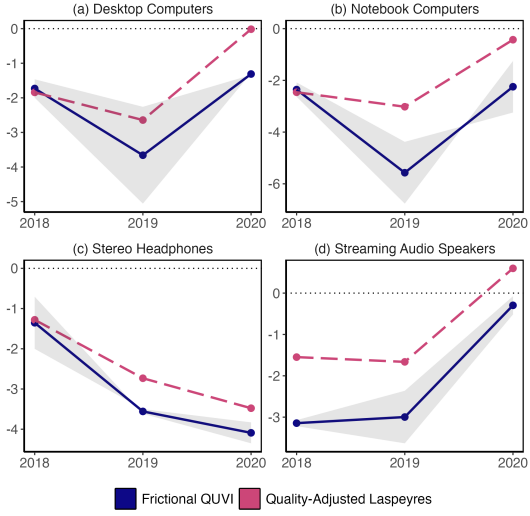
Implementing the Frictional QUVI

The Frictional QUVI versus the Quality Adjusted Laspeyres

- We isolate the additional effects of price dispersion in the QUVI relative to the quality adjusted Laspeyres:

$$\left(\frac{S_t^c}{S_{t-1}^c}\right)^{-1}\left(\sum_{k\in C} s_{kt}^c\left[\frac{\omega_{kt}}{\omega_{kt-1}}\right]^{-1}\right)^{-1}$$

- Accounting for wedges lowers QUVI by 1 p.p. on a quarterly basis compared to quality adjusted Laspeyres



Decomposing the Frictional QUVI

	Within	Continuers	Net-Entry	FQUVI
	(1)	(2)	(3)	(4)
Desktop Computers	−1.86	−10.92	10.06	−2.72
Notebook Computers	−2.17	−16.68	15.67	−3.18
Stereo Headphones	−2.49	−4.82	3.66	−3.65
Streaming Audio Speakers	−1.79	−4.70	3.41	−3.08

- Average price change within continuing goods accounts for two-thirds of decline
- Remaining kick comes from consumers shifting purchases towards lower priced goods over their life-cycle holding quality constant

The Frictional QUVI Compared to Alternative Indices

			Redding-Weinstein		
	FQUVI	Erickson-Pakes	No CGR	30p CGR	50p CGR
	(1)	(2)	(3)	(4)	(5)
Desktop Computers	−24.7	−16.2	−25.0	−22.2	−21.2
Notebook Computers	−36.1	−27.4	−49.1	−43.6	−38.9
Stereo Headphones	−32.2	−30.2	−57.4	−52.2	−50.8
Streaming Audio Speakers	−23.9	−29.6	−63.8	−52.0	−46.4

- Comparing 2017q4-2020q4 cumulative inflation to alternative hedonic Tornqvist based on Erickson and Pakes (2011) and CES unified price indices from Redding and Weinstein (2020)
- The common goods rule (CGR) for CES indices restricts common goods to those above the N-th percentile in expenditure shares

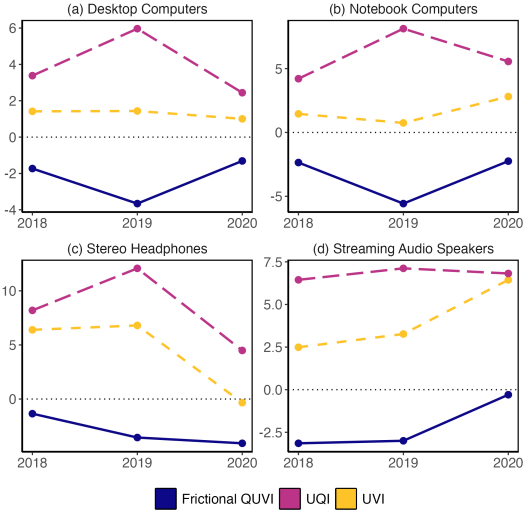
Redding and Weinstein (2020)

An Implied Measure of Quality Growth

- Ratio of the UVI and the frictional QUVI backs out measure of quality growth (unit *quality* index, UQI):

$$\text{UQI} = \text{UVI}/\text{FQUVI} \qquad (1)$$

- Average quarterly quality growth is approximately 6 percent across goods
- Hence UVI is propped up primarily as a result of quality growth



Decomposing Quality Growth in the UVI

	Within	Continuers	Net-Entry	UQI
	(1)	(2)	(3)	(4)
Desktop Computers	0.35	−7.37	11.69	5.08
Notebook Computers	0.60	−13.61	16.87	4.38
Stereo Headphones	1.05	4.47	4.77	11.15
Streaming Audio Speakers	0.49	−0.34	3.70	4.90

- Applying FHK decomposition to UQI to understand sources of quality growth
- Average quality growth for continuing goods is dwarfed by shifts in consumption
- Quality growth occurs primarily through purchase new high quality items in line with Malthusian role of product turnover

Conclusion

Conclusion

- We account for important features when defining quality difference:
  1. Time varying quality measures
  2. Tracking residual price dispersion
- Our implementation of a frictional QUVI are similar in magnitude in alternative hedonic and demand-based indices
- Lastly, we show how to decompose rich information embedded in the UVI

Thank you!

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Additional Slides

FHK Decomposition of the QUVI

– Similar to the decomposition of the UVI, the QUVI breaks up into Within, Continuers, and Net-Entry terms:

$$\text{QUVI} = 1 + S^{c}_{t-1} \sum_{k \in C} s^{c}_{kt-1} \left(\frac{p_{kt}/\lambda_{kt}}{p_{kt-1}/\lambda_{kt-1}} - 1 \right) + \sum_{k \in C} \Delta\omega_k \left(\frac{p_{kt}/\lambda_{kt}}{P_{t-1}} \right) + \sum_{k \in N} \omega_{kt} \left(\frac{p_{kt}/\lambda_{kt}}{P_{t-1}} \right) - \sum_{k \in X} \omega_{kt-1} \left(\frac{p_{kt-1}/\lambda_{kt-1}}{P_{t-1}} \right)$$

where QUVI has a direct connection to the quality adjusted Laspeyres

– Note the weighting scheme of the QUVI relies on quality adjusted quantity weights ω_{kt} as opposed to quantity weights as in the UVI

QUVI as an Exact Price Index

Outline of Redding and Weinstein (2020)

- Redding and Weinstein (2020) calculates the exact price index under the CES aggregator with time-varying product appeal ϕ_{kt}:

$$Q_t = \left(\sum_{k \in \Omega_t} \left[\phi_{kt} q_{kt} \right]^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

- To recover product appeal terms, authors assume that unweighted geomean of product appeal for continuing goods is constant between periods:

$$\tilde{\phi}_{t-1} = \prod_{k \in C} \phi_{kt-1}^{1/|C|} = \prod_{k \in C} \phi_{kt}^{1/|C|} = \tilde{\phi}_t$$

- CES exact price index simplifies to the following expression:

$$\frac{P_t}{P_{t-1}} = \left(\frac{S_t^C}{S_{t-1}^C} \right)^{\frac{1}{\sigma-1}} \left(\prod_{k \in C} \left[\frac{s_t^C}{s_{t-1}^C} \right]^{\frac{1}{|C|}} \right)^{\frac{1}{\sigma-1}} \left(\prod_{k \in C} \left[\frac{p_t}{p_{t-1}} \right]^{\frac{1}{|C|}} \right)$$