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QUANTIFYING QUALITY GROWTH

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ABSTRACT

We introduce an instrumental variables approach to estimate the importance of unmeasured quality growth for a set of 66 durable consumer goods. Our instrument is based on predicting which of these 66 goods will display rapid quality growth. Using pooled cross- *relatively* sections of households in the 1980 through 1996 U.S. Consumer Expenditure Surveys, we estimate "quality Engel curves" for 66 durable consumer goods based on the extent richer households pay more for a good, conditional on purchasing. We use the slopes of these curves to predict the rate of quality-upgrading. Just as if households are ascending these quality Engel curves over time, we find that the average price paid rises faster for goods with steeper quality slopes. BLS prices likewise increase more quickly for goods with steeper quality slopes, suggesting the BLS does not fully net out the impact of quality-upgrading on prices paid. We estimate that quality growth averages about 3.7% per year for our goods, with about 60% of this, or 2.2% per year, showing up as higher inflation rather than higher real growth.

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1. Introduction

As people get richer they consume not only more goods but better goods. Quantifying such quality growth is difficult. Because of exacting data requirements, the hedonic techniques pioneered by Griliches (1961) and Adelman and Griliches (1961) are still only applied to a limited number of goods (e.g., cars, houses, computers). Shapiro and Wilcox (1996, p. 124) describe the measurement of quality change as necessitating "house-to-house combat", i.e., detailed good-by-good studies. The Boskin Commission (1996) cites only a handful of studies in arriving at its estimate that unmeasured quality change biases the U.S. CPI upward by about 0.6% per year.[1]

We introduce an instrumental variables approach to estimating the rate of quality growth. We apply this approach to estimate the overall importance of unmeasured quality growth for 66 durable consumer goods (see Table 1 for a list of the goods). Our instrument is based on predicting which of these 66 goods will display *relatively* rapid quality growth.

Our approach can be briefly described as follows. The growth rate in unit prices for any good reflects both growth in the average quality of the good and the true rate of price inflation (the rate of price increase holding quality constant):

$$(1) \qquad \text{Unit-price inflation} = \text{Rate of quality growth} + \text{True inflation}\,.$$

Ideally, the government controls for quality changes, producing a measure of inflation equal to the true rate of inflation. But suppose that the government can capture only part of quality changes, with a fraction μ of quality-driven price increases inadvertently recorded as price inflation:

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[1] Including studies on new goods as well as higher quality within a category, the Boskin Commission cites Randolph (1988) on housing, Gordon on durable goods (1990), Trajtenberg (1990) on medical imaging devices, Berry, Kortum and Pakes (1996) on new cars, Griliches and Cockburn (1994) on prescription drugs, Cutler et al. (1996) on heart attack treatment, Hausman on breakfast cereal (1997a) and cell phones (1997b), and Nordhaus (1997) on lighting.

$$\text{(2)} \qquad \text{Measured inflation} = \text{True inflation} + \mu(\text{Rate of quality growth}) .$$

(1) and (2) imply that measured inflation can be related to unit-price inflation as

$$\text{(3)} \qquad \text{Measured inflation} = \mu(\text{Unit-price inflation}) + (1 - \mu)(\text{True inflation}).$$

Our approach is to estimate μ from regressing measured inflation on unit-price inflation, as in (3), with $(1 - \mu)$(True inflation) as an error term. But we first instrument for unit-price inflation, as dictated by equation (1), with one or more variables that predict rapid quality growth, yet are arguably uncorrelated with true inflation.

We construct such an instrument by exploiting "quality Engel curves" that we estimate from pooled cross-sections of household data (1980 to 1996 U.S. Consumer Expenditure Surveys). Whereas a traditional Engel curve traces out total expenditures on a good against permanent income or wealth (which we proxy with overall consumption), a quality Engel curve traces out the *unit price* of a good against overall consumption.[2] Our premise is that, across households at a point in time, those paying higher prices are buying higher quality goods (perhaps bundled with more retail services). Not surprisingly, richer households buy more expensive goods so that the estimated slopes are all positive and significant. Averaging across the goods, the quality portion comprises 56% of the overall Engel Curve, suggesting a potentially important role for quality growth in consumption growth.

Our instrument is based on the relative steepness of the quality Engel curves across the 66 goods. For instance, we see that richer households buy much more expensive automobiles than poorer households, whereas richer households spend only modestly more than poorer households in purchasing a vacuum cleaner. Thus, as households on average become richer, we predict faster quality growth for automobiles than for vacuums. Assuming goods with steeper Engel

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[2] The overall Engel curve is the product of the quality Engel curve and a *quantity* Engel curve, where the latter traces out the number of units bought against overall consumption.

curves do not display systematically faster or slower true inflation over time, a good's *relative* Engel curve provides our instrument for quality growth (and unit-price inflation) for equation (1).

We find that our estimated quality Engel curve slopes are highly correlated with unit price changes for the 66 goods (correlation coefficient of .51). That is, those goods with steeper quality Engel curves display faster rising average unit prices over 1980 to 1996. This is precisely what one would expect if households are climbing up their quality Engel curves over time. We estimate that quality-upgrading occurs at the rate of about 3.7% per year on average for the 66 goods.

Since the U.S. Bureau of Labor Statistics (BLS) makes explicit adjustments for quality change in constructing its price indices, the quality-upgrading that we find reflected in unit price changes need not show up in BLS price changes at all. (That is, estimating equation (3) could produce $\hat{\mu} = 0$.) We find, however, that goods with steeper quality Engel curves do display faster rising BLS prices. We estimate that, over 1980-1996, the BLS deflators adjusted for only about 40 percent of the predicted differences in quality growth across goods, with the remaining 60 percent showing up as higher BLS inflation. The BLS netted off a little under 1.5% per year for quality growth for our 66 goods from 1980-1996. If this represents only 40 percent of all quality growth during the period, then the BLS understated quality growth and overstated inflation by 2.2% per year for our 66 goods.

The paper proceeds as follows. In section 2 we lay out a simple model in which rising household purchasing power generates rising demand for quality. This model features cross-sectional quality Engel curves specific to each good that provide an instrument for our IV approach to estimating quality growth. In section 3 we present the time-series behavior of unit-price and BLS-price inflation rates for our 66 goods. In section 4 we estimate quality slopes for the 66 goods using household data. In section 5 we exploit the quality slopes estimated off of cross-sectional data to predict the rate of quality upgrading over time, and test the extent to which BLS prices (improperly) rise with quality upgrading. Section 6 concludes.

2. A Model for Estimating Quality Engel Curves and Predicting Growth in Quality

The typical model of quality improvements (e.g., Aghion and Howitt, 1992) focuses on firm incentives to design higher quality goods. The preference side of the model is usually kept simple. Consumers prefer higher quality, but are willing to substitute with infinite elasticity among different qualities. We will present evidence that, in contrast, different levels of quality are imperfect substitutes in the eyes of consumers. Richer households typically buy more expensive, higher quality versions of goods. In this section we lay out a simple model which has this feature. We derive quality Engel curves that relate the quality of good purchased (measured by price paid) to a consumer's wealth and consumption. In turn, the relative slopes of the quality Engel curves predict which goods should exhibit faster rates of quality improvement over time.

Household Quality Choices

Households maximize lifetime utility given by

$$U_0 \;=\; \sum_{t=0}^{\infty} \beta^t u_t \,.$$

β is the discount factor. u_t is utility derived during period t. We abstract from uncertainty, allowing for a constant growth rate of real income and expenditures.

Utility derived in any period is given by

$$u \;=\; \frac{c^{1-1/\sigma}-1}{1-1/\sigma} \;+\; \sum_{i=1}^{N} \begin{cases} \widetilde{v}_i \; \dfrac{[q_i^{1-1/\sigma_i}-1]}{1-1/\sigma_i} & \text{if } q_i > 0 \\ 0 & \text{if } q_i = 0 \end{cases} \,.$$

A time subscript is implicit. The household chooses the quality, indicated by q_i, of *N* different durable, indivisible goods (*i* = 1, ... , *N*). The household may choose not to own durable good *i* at all, in which case $q_i = 0$.[3] The household also buys an effective amount (quality times quantity) *c* of a composite divisible, nondurable good. We separate out divisible goods because these are the ones for which "unit prices" (the price paid for a unit of the good, such as for a single refrigerator) are observable in the Consumer Expenditure Surveys of U.S. households. $\tilde{\nu}_i$ is the preference "intercept" for good *i*, and the σ_i's and σ govern the curvature of utility for the goods. We assume that $\sigma > 0$ and $\sigma_i > 0 \; \forall \; i$.

We assume that good i has a deterministic life of τ_i periods. Therefore, a household owns good *i* if it purchased the good in this or one of the preceding $(\tau_i - 1)$ periods. We do not treat τ_i as a choice dimension of quality. We assume consumers keep the good for the full τ_i periods. Thus consumers do not trade in used goods, which we think is realistic for most of the goods we examine. This requires that the desired growth in quality over the life τ_i of a good is not so fast that consumers would choose to discard a working durable to upgrade its quality.

The household budget constraint is

$$c + \sum_{i=1}^{N} \Omega_i x_i = y$$

where:

$$x_i = z_i q_i .$$

The price of nondurable consumption *c* is normalized to one. *y* is household expenditure, which in turn equals income minus the change in assets. Ω_i is 1 if the household purchases durable i in the current period, and 0 otherwise. x_i is the *unit price* of good i relative to the price of the nondurable.

For a given type of product (say televisions) the household faces a menu of quality-price combinations from which to choose. The menu slopes upward, so that higher quality versions

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[3] Subtracting 1 inside the brackets means utility from the good is positive only if $q_i > 1$. i.e., it is not worth buying the good unless one buys a sufficiently high quality version. This contributes to some households not owning certain goods at all, as does $\tilde{\nu}_i = 0$ for some households. This functional form also allows utility to be positive even when $\sigma_i < 1$.

are more expensive.[4] Facing the menu, the household chooses whether to buy a good and, if so, what quality level to buy. The unit price x_i reflects both the quality-adjusted price and the level of quality: z_i represents price *holding quality* q_i *constant*. We assume that the relative price of differing qualities of a good are determined by relative production costs, given competitive pricing.[5] Moreover, this rate of transformation between lower and higher quality versions is unaffected by relative or total quantities produced. (Rosen, 1974, considers somewhat more general assumptions.)

Consumers must decide whether to consume good *i* and, if so, at what quality. We focus on the latter of these decisions, treating quality q_i as a continuous choice variable. Conditional on good *i* being purchased, the household equates the ratio of marginal utilities of q_i (derived over the subsequent τ_i periods) and *c* to the ratio of their prices:

$$\frac{\tilde{v}_i q_i^{-1/\sigma_i}\left(\frac{1-\beta^{\tau_i}}{1-\beta}\right)}{c^{-1/\sigma}} = z_i \, .$$

Rearranging and taking natural logs yields

$$\ln q_i = \theta_i \ln c - \sigma\theta_i \ln z_i + \ln v_i \tag{4}$$

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[4] We define quality in price terms, so that a doubling of quality doubles price. Our results are robust to assuming a more general elasticity, ϕ_i, of price with respect to quality, i.e., $x_i = z_i q^{\phi_i}$. What is important for the consumer's problem is the extent of diminishing returns to spending on quality. These diminishing returns can either reflect diminishing utility flow from quality because $\sigma_i < \infty$, or a rising price of quality from $\phi_i > 1$.

We have also considered the possibility that the *relative* price of quality for good *i* rises or declines over time through changes in the parameter ϕ_i. Changes in ϕ_i will be reflected in a changing slope of the quality Engel curve discussed below. We find, however, that for most of our 66 goods we cannot reject constancy of the quality Engel curve from 1980 to 1996. (See section 4.)

[5] Our results are unlikely to reflect departures from competitive pricing. For one, we find in section 4 that if Household A has twice the nondurable consumption of Household B, Household A typically pays about 76 percent more for a consumer durable. It is unlikely that much of this difference reflects the rich paying higher price markups, *conditional* on quality. In fact, Goldberg (1996) finds no correlation between the price a household pays for a particular car model and the household's income, financial assets, education or occupation. Secondly, our IV estimates are robust to richer consumers paying higher markups for the same good, provided the impact of wealth on the markup does not vary much across goods. Thirdly, if differences across goods in the slopes of the quality Engel curves largely reflect richer households paying a higher markup for certain goods, rather than purchasing a higher quality, then we should not find that our quality slopes systematically predict which goods exhibit faster unit-price and BLS-price inflation from 1980 to 1996.

where: $$\theta_i = \frac{\sigma_i}{\sigma}, \text{ and } v_i = \left(\frac{\tilde{v}_i(1-\beta^{\tau_i})}{1-\beta}\right)^{\sigma\theta_i}.$$

Expression (4) shows that, conditional on buying good *i*, a household will want to buy a higher quality version the richer they are (the higher is *c*), the lower the quality-adjusted price of the good (the lower is z_i), and the greater their preference for the good (the higher is v_i).

From (4), the elasticity of demand for quality with respect to *c* is θ_i. We call this the slope of the "quality Engel curve" for good *i*, or "quality slope" for short. It maps out how a household's demand for quality (expressed in price units) rises as its consumption of nondurables rises. Good *i*'s quality slope is steep if there is little curvature in preferences with respect to q_i (i.e., if σ_i is high).

Note that the quality slope is important not only for how quality responds to consumption *c*, but also to shifts in z_i, the price of good *i* holding quality constant. Suppose the cost of producing good *i* increases one percent, raising z_i by one percent. If there is no response in the level of quality bought, the unit price of *i* rises by one percent. But equation (4) shows that this increase in z_i will induce the quality of good *i* purchased to fall by $\sigma\theta_i$ percent. Thus, if $\sigma\theta_i > 1$, an increase in z_i actually results in a fall in the unit price of good *i*.

Predicting Growth in Quality

We draw a distinction between how quality upgrading affects inflation in unit prices versus BLS-measured prices. The growth rate of unit prices reflects the sum of quality growth and "true inflation" (the growth in prices holding average quality constant):

$$\Delta x_i = \Delta q_i + \Delta z_i \,.$$

(Here Δx denotes the growth rate – i.e. log first difference – of *x*. Time subscripts are implicit.) In contrast, BLS inflation rates aim to measure price changes holding quality constant. We refer to the BLS inflation rate for good *i* as Δp_i. If the BLS measure is perfectly unaffected by changes in quality, then it equals Δz_i. If, instead, the BLS is able to net out only a fraction $(1-\mu)$ of quality growth, then Δp_i is given by

$$\Delta p_i = \Delta z_i + \mu \Delta q_i \quad .$$

These two equations yield the relation between BLS and unit-price inflation

(5) $$\Delta p_i = \mu \Delta x_i + (1-\mu)\Delta z_i \ .$$

Our strategy is to estimate μ by regressing BLS-price inflation on unit-price inflation, as in (5), treating $(1-\mu)\Delta z_i$ as an error term. Of course, unit-price inflation is clearly correlated with true inflation Δz_i, as unit-price inflation reflects the sum of quality upgrading and true inflation. The key is to instrument for unit-price inflation with variables that predict a good's rate of quality upgrading but are arguably orthogonal to its true inflation rate. We exploit differences across goods in the slopes of their quality Engel curves (θ_i's) to construct these instruments.

From equation (4) the growth rate of quality for good *i* is given by

$$\Delta q_i = \theta_i \Delta c - \sigma \theta_i \Delta z_i + \Delta v_i \, .$$

Δc refers to the average growth rate of *c* for the economy (weighting individual household growth rates equally). Δv_i reflects common growth in preferences for good *i*. The above expression says that goods with steeper quality slopes (larger θ_i's) should exhibit faster growth in average quality in response to economy-wide income and consumption growth ($\Delta c > 0$). Quality should also rise faster for goods with declining relative prices ($\Delta z_i < 0$). This is particularly true if the good has a steep quality slope.

Substituting the expression above into (5), unit-price inflation equals

$$\Delta x_i = \theta_i \Delta c + (1 - \sigma\theta_i)\Delta z_i + \Delta v_i \,. \tag{6}$$

The first term says that goods with steeper quality slopes display faster growth in unit prices in response to economy-wide consumption growth, reflecting their faster growth in quality. This suggests differences across goods in the quality slopes θ_i as a relevant instrument for differences in unit-price inflation Δx_i in (5). Below we estimate separate quality slopes for 66 consumer durables using cross-sections of the Consumer Expenditure Survey. We find important differences across goods in their estimated quality slopes. Furthermore, these differences are excellent predictors of which goods display faster unit-price inflation. The correlation between a good's quality slope and its rate of unit-price inflation is 0.51.

Our identifying assumption is that differences in the estimated quality slopes across goods (θ_i's) are uncorrelated with quality-adjusted relative price shifts across goods (Δz_i's):

$$\text{cov}(\theta_i, \Delta z_i) = 0 \quad \text{across } i. \tag{7}$$

If (7) holds, then θ_i is a valid instrument for Δx_i in equation (5).[6]

The conjectured relationship between the unit price x_i, the BLS price p_i, and nondurable consumption c is depicted in Figure 1 for two goods (vacuums and cars). In period 0, unit and BLS prices are normalized to be equal for each good ($x_0 = p_0$). From period 0 to period 1 growth in nondurable consumption generates an increase in quality and unit price for good i equal to $\theta_i \Delta c$. The figure is drawn such that θ_i is larger for cars than for vacuums; cars exhibit the relatively steeper quality slope. (This is consistent with estimates below.) For this reason, the increase in x_i from x_0 to x_1 is much larger for cars than vacuums. In contrast, if the BLS price

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[6] More formally, the condition is $\lim_{Nk \to \infty} \left(\frac{\sum_{i=1}^{N} \theta_i (\ln z_{it} - \ln z_{it-k})}{Nk} - [\frac{1}{N}\sum_{l=1}^{N} \theta_l][\frac{1}{Nk}\sum_{l=1}^{N}(\ln z_{lt} - \ln z_{lt-k})] \right) = 0.$

reflects only quality-adjusted prices, then the growth in p_i, from p_0 to p_1, should not be predictably greater for cars than vacuums. Figure 1 actually depicts no changes in quality-adjusted prices, or $\Delta z_i = 0$ for both cars and vacuums; there are no shifts in the curves, so the BLS prices should not change at all. But to the extent μ is greater than zero, faster growth in x_i for cars than vacuums will be mirrored in faster growth in p_i. As drawn, two-thirds of the faster growth in the quality and unit price of cars relative to vacuums shows up as faster BLS inflation for cars. This would identify a value for μ of 2/3.

We can construct another instrument for quality growth by interacting the change in quality-adjusted prices with θ_i. To see this, first rewrite equation (6), ignoring constant terms, as

$$\Delta x_i = \theta_i(\Delta c - \sigma\Delta z) - \sigma(\theta_i - \theta)(\Delta z_i - \Delta z) + (1 - \sigma\theta)\Delta z_i + \Delta v_i,$$

where $\theta = \frac{1}{N}\sum_{i=1}^{N}\theta_i$ denotes the average value of θ_i across goods, and $\Delta z = \frac{1}{N}\sum_{i=1}^{N}\Delta z_i$ denotes the average true inflation rate across goods. This expression suggests the interaction term $(\theta_i - \theta)\Delta z_i$ as a second relevant instrument for the growth rate of unit prices. It captures the feature that quality will respond most dramatically to a change in z_i for a good with an especially steep quality slope. Validity of $(\theta_i - \theta)\Delta z_i$ as an instrument requires an assumption that parallels equation (7), but with the quality slopes uncorrelated with $(\Delta z_i)^2$ rather than with Δz_i.

Construction of the instrument $(\theta_i - \theta)\Delta z_i$ is complicated by the fact that Δz_i is only equal to BLS inflation for good *i* if $\mu = 0$. But, rearranging equation (5), Δz_i can be related to BLS inflation and unit-price inflation, equaling $\frac{1}{1-\mu}\left(\Delta p_i - \mu\Delta x_i\right)$. This construction is conditioned on a value for μ, the parameter of interest. Therefore, its use in constructing another instrument entails nonlinear estimation of μ. We return to these issues in Section 5.

Given an estimate for μ, we can also calculate a measure of quality growth and unmeasured quality growth for our set of consumer durables. If the BLS succeeds in precisely netting out the impact of quality change, then an estimate of quality change is provided simply by the growth rate in unit prices for good *i* minus its BLS rate of price increase. When $\mu > 0$, however, quality growth equals $(\frac{1}{1-\mu})$ times this difference:

(8)
$$\Delta q_i = \frac{\Delta x_i - \Delta p_i}{1-\mu} \ .$$

Given a value of μ, it is straightforward from (8) to estimate the amount of quality growth across our 66 goods. The extent of *unmeasured* quality growth is similarly given by $\frac{\mu(\Delta x_i - \Delta p_i)}{1-\mu}$.

3. Comparing Unit-Price and BLS-Price Inflation

Consumer Expenditure Data

We construct measures of unit-price inflation for each of 66 consumer durables based on household spending reported in the 1980 to 1996 Consumer Expenditure Surveys (CEX) conducted by the Bureau of Labor Statistics.[7] As discussed in the next section, we also use cross-sections of the CEX as our data for estimating quality Engel curves for each of the goods.

The CEX has a rotating sample of about 5,000 households. Each household is maintained in the sample for a year, encompassing four quarterly surveys. The CEX asks respondents how much they spent over the previous quarter on a wide array of goods and services. Expenditures are typically assigned to a particular month in the quarter. If an expenditure can be associated with a particular unit purchase, then we can assign a unit price to the purchase of that good. From all the goods surveyed by the CEX, we chose 66 goods for which purchases tend to be quite distinct.[8] We were also restricted by the requirement that the BLS produce a price deflator for the good for all or much of the 1980 to 1996 period. The goods are listed in Table 1.

These 66 goods constitute 81.3% of a household's spending on durables as reflected in the December 1997 weights for constructing the CPI. They represent 12.4% of the overall CPI. (We report the CPI weight for each good in column 1 of Table 3, which we discuss further below.)

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[7] The Bureau of Labor Statistics conducts two separate surveys of consumer expenditures: an interview survey and a diary survey. Our data are based on the interview surveys.

[8] If a respondent purchases more than one of the same category of good in the same month (e.g., bicycles) the survey may report them separately. But it is conceivable that the amounts can be lumped together. If so, then our quality Engel curve estimates may be biased upward. This would not compromise the validity of our instruments if it merely scaled up all of our estimates proportionately.

For the years 1994 to 1996 the CEX asks households to state explicitly the number of items purchased for each of the clothing categories, as well as for watches and jewelry. Thus for years 1994 to 1996 we can compare these responses to the quantities we obtain by summing the number of itemized purchases in each category of goods. For these goods we find a tendency for our base calculations to understate somewhat the number of goods purchased, consistent with some lumping. But of much more relevance to our work, the extent of this discrepancy is typically only very weakly related to household nondurable consumption. Based on these comparisons for years 1994 to 1996, we rescale the quantities for each of the clothing categories, watches, and jewelry to correct for the extent our quantities systematically deviate from the responses to the more direct question on number of items purchased. We also condition on family total nondurable consumption, as well as additional controls (e.g., age of household head), in rescaling these quantities. These corrections also modify the unit prices. Our results are not sensitive to these small adjustments.

The first column of Table 1 reports, for the pooled 1980 to 1996 cross-sections, the number of households who reported purchasing each good. These numbers provide the sample sizes for estimating the quality slopes in Section 4. The second column presents the fraction of the sample buying. This ranges from a low of 1.7% for sewing machines to a high of 63.3% for women's footwear. The final column reports what fraction of those purchasing a good report more than one purchase in the 12-month period. This fraction is highest for boys' and girls' footwear.

Unit-price inflation

We measure increases in unit prices for the 66 goods as follows. Expenditures are grouped by year of purchase. We can then construct for each good the average price paid across households by year for 1980 to 1996.[9] Across the 66 goods we have 1,469,561 unit-price observations. We then divide each unit price by the CPI for nondurables in the same year (our numeraire). To minimize the impact of outliers in a particular year, we calculate a three-year centered moving average of these prices. Finally, we calculate the annual percentage rate of inflation for each good based on comparing this moving average for 1995 to its value for 1981.[10]

The resulting inflation rates appear in the first column of Table 2. The CPI-weighted average unit prices for these 66 durables rose by 0.97% per year relative to the CPI for nondurables. The most extreme declines were for microwave ovens (-9.2%) and heaters (-4.1%). The most extreme increases were for trucks (3.7%), sports and exercise equipment (2.8%), and jewelry (2.8%).

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[9] Expenditures are weighted by a CEX sampling weight for each household. For 12 of the 66 goods we actually calculate inflation rates at a slightly finer level of aggregation than in Table 2. For instance living room furniture is separated into tables versus chairs; men's and boy's sleepwear, as well as sweaters, are separated for men's versus boy's; winter sporting goods are separated from water sporting goods. We aggregated goods in these 12 cases largely in order to be consistent with BLS categories. We aggregate on the basis of expenditure shares in the CEX. Similarly, in Section 4, the quality Engel curves for these 12 goods are estimated including a dummy variable to control for the finer category of good being purchased, e.g., is the good men's sleepwear or boys' sleepwear.

[10] For two of the goods, calculators and typewriters, data begin in 1982; for telephones data begins in 1983.

BLS Inflation

BLS price indices are not the same as CEX unit prices for a number of reasons. One important reason is that the BLS collects prices on goods at a finer level of detail than the CEX categories and leaves the weight on each item unchanged from period to period. In contrast, average unit prices reflect current (and therefore changing) weights.[11] If people switch toward more expensive CPI models within a CEX category, then the average unit price for the category should rise but the BLS price index for the category need not. The BLS fixed weighting scheme means it does not register a price change when consumers switch among items with different, but themselves unchanged, prices. This is true even if the BLS collects prices on only a single model in a CEX category.

Although the fixed-weight scheme could prevent quality upgrading from contaminating BLS price changes, the protection is not complete because many models disappear, forcing the BLS to price different items from one period to the next. The items which disappear may be replaced with higher quality goods, and the associated quality improvements may not be fully netted out from the BLS inflation rate. Moulton and Moses (1997) describe BLS "item substitution" procedures in detail. They report that about 30% of BLS items disappear at least once every year (p. 323). Moreover, in the three years which have been studied, replacement items contributed disproportionately to the overall CPI inflation rate. Even excluding apparel, in which items tend to get marked down before being replaced by full-priced items, replacement items represented 2.6%, 2.7%, and 3.2% of price quotes in 1983, 1984, and 1995, but accounted for 20%, 34%, and 31% of the non-apparel inflation rate in those years (see their Tables 5 and 6,

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[11] In 1996 the BLS collected price quotes for goods in around 200 categories, most corresponding to the CEX categories. On a monthly basis, they collected about 100,000 price quotes across 44 geographical areas. According to Moulton (1996), the mean number of price quotes per category-area was 13 in May of 1996. There were not 13 distinct models per category, however, since some were the same model at different outlets. The BLS does not tabulate the number of distinct models for which prices are collected per category.

A more minor distinction between BLS and unit prices is that the BLS only updates the establishments at which it collects prices every five years. Thus a shift toward, say, discount outlets would tend to make CEX unit prices rise more slowly than BLS prices. Both Shapiro and Wilcox (1996) and the BLS estimate such "outlet bias" to be about 0.1% per year.

p. 338-340). These figures indicate that item substitutions coincide with disproportionately rapid BLS inflation and, perhaps, unmeasured quality improvements.

The item substitution rate is even higher for the consumer durables that we examine than for the average item in the CPI. Column 2 of Table 3 contains the monthly item-substitution rates for the 66 goods we study. These numbers were made available to us by the BLS, and are for 1997. The substitution rate varies from 2.4% per month for calculators and typewriters to 38.3% for women's and girls' dresses, and averages 13.8% across the goods when each good is weighted by its share of the December 1997 CPI (the weights are given in column 1). In contrast, the monthly substitution rate for all items in the CPI was 3.8% in 1997.

Conditional on the need for an item substitution, the BLS follows one of three procedures. In roughly one-half of these cases (see Shapiro and Wilcox, 1996, p. 99) the BLS finds a replacement item it judges to be "comparable" to the old item, and makes no quality adjustment. Column 3 of Table 3 reports the percent of substitutions judged comparable for our goods. It is the most common procedure, occurring 46% of the time for our goods (weighted by their CPI share). In certain cases the BLS makes a direct quality adjustment, involving either hedonic pricing or the manufacturer's estimate of the cost of producing the new item relative to the displaced item. Column 4 reports that this occurs only 22% of the time for our goods. It is most common for trucks, cars, and mens' suits. In the rest of the cases the BLS scales the entry price of the replacement item so that the item's inflation rate matches that of other items in the same category for that month. This usually entails scaling the entry price down, and therefore netting out some of the higher price of the new good as reflecting superior quality. For 1995, Moulton and Moses (p. 343) find that BLS quality adjustments reduced the CPI inflation rate by between 0.28% and 0.44%. Column 5 of Table 3 reports that this procedure was used in 32% of item substitutions for our goods. For the majority of the item substitutions for our goods (78%), the BLS made no direct quality adjustment. This underlines the possibility that many item substitutions could involve unmeasured improvements in quality that should have been (but were not) netted out of the BLS inflation rate for those goods.

To summarize, if the BLS deflator perfectly measured price per unit of quality, then μ would be zero. If the BLS understated quality improvements and overstated inflation, then μ would be positive. As stressed by Triplett (1997), however, the BLS could have actually overstated quality improvements and understated inflation, in which case μ would be negative.

In Table 2 we compare the BLS measures of price inflation to our constructed measures of unit-price inflation good by good. The rate of unit-price inflation, as discussed above, appears in Column 1. The rate of BLS inflation appears in Column 3. The BLS rates of inflation, like our unit-price inflation rates, are expressed relative to the BLS rate of inflation for nondurables. To be comparable to our construction of the unit prices, the BLS inflation rates are also based on a 3-year moving average of deflators. Across the 66 goods the correlation between the unit-price changes in Column 1 and the BLS price changes in Column 3 is 0.48. Figure 2 plots each good's rate of BLS-price inflation versus its rate of unit-price inflation. Microwaves is clearly an outlier in terms of both inflation rates. Dropping microwaves from the sample reduces the correlation between the two inflation rates from 0.48 to 0.33.

BLS deflators are not available for the full 1980-1996 period for all 66 goods. For 26 goods the BLS sample period is shorter than 1980 through 1996 (see the notes to Table 2). Column 2 provides the rate of unit-price inflation for the time period that the BLS price deflator is available. Comparing Columns 2 and 3, the BLS-price inflation rates are systematically lower than the unit-price inflation rates, presumably reflecting BLS adjustments for quality improvements. The last column in Table 2 reports the rate of inflation in unit prices minus the rate of BLS inflation. We calculate this difference using unit-price inflation over the same period that the BLS inflation rate is available (i.e., we calculate it as Column 2 minus Column 3). The mean difference across the 66 goods is 1.46% lower inflation per year in BLS prices than in unit prices (both BLS prices and unit prices are CPI-share-weighted). An interpretation of this is that the BLS, on average across these goods, incorporates quality growth of 1.46% per year.[12]

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[12] The unit-price and BLS-price inflation rates also differ because the BLS weights (on outlets and on goods within CEX categories) move only gradually, whereas current weights are embedded in average unit prices.

4. Estimating Quality Engel Curves from cross-sections of households

We employ CEX cross-sections of households for 1980 to 1996 to estimate a separate quality Engel curve for each of the 66 goods in Table 4. The estimate of a good's quality slope θ_i is based on how the unit-price that a household pays for a good, say televisions, is related to a household's total nondurable consumption.

Starting from equation (4), it is straightforward to solve for the unit price paid by a household for good *i*. Adding a household subscript *j*, and ignoring terms that do not vary across households, we have

$$\ln \widehat{x}_{ij} \;=\; \theta_i \ln \widehat{c}_j \;+\; \ln v_{ij} \;+\; \epsilon_{ij}\,, \tag{9}$$

where:

$$\epsilon_{ij} \;=\; \ln\Big(\frac{\widehat{x}_{ij}}{x_{ij}}\Big) \;-\; \theta_i \ln\Big(\frac{\widehat{c}_j}{c_j}\Big)\,.$$

$\widehat{x}_{ij}$ and $\widehat{c}_{ij}$ denote a household's reported values for x_{ij} and c_{ij}.[13] The distinction between the reported and true values for x_{ij} and c_{ij} contributes the error term ϵ_{ij}. In arriving at (9) we are assuming that households face the same quality-adjusted prices z_i. In pooling cross-sections of households from different years of the CEX, we add dummies for year, region, and city (vs. rural) to control for likely differences in prices across time and space. In addition to heterogeneity in c_j, we allow for heterogeneity in the household's preference for each good by including a number of household characteristics as control variables. The household characteristics are number of persons and number of children in the household, average age of the household head and that age squared, and dummy variables for single male-headed households, and for single female-headed households. We interpret these variables as shifting v_{ij} in (9).[14] For five of the goods (carpeting,

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[13] Conditional on a household reporting more than one purchase of a good, we average the expenditures to arrive at a unit price.

[14] Additional variation in this preference parameter is another potential source of error in equation (9). Selection of household *j* into the sample of purchasers of good *i* based on the household's value of v_{ij} could bias the estimates of θ_i downward. If poorer households are less likely to buy a good, then poorer households in the sample of purchasers will be those with a high preference for the good (a standard Heckman self-selection problem). It is not clear how this selection will bias the *relative* estimates of θ_i across goods, which is central to

curtains and drapes, window coverings, lamps and lights, and hardwood flooring), we are concerned that richer households may buy a larger size or quantity, as well as higher quality. For these goods we also control for the number of rooms in the household's home.

We define c_j in (9) to be a household's total nondurable consumption. Our measure of nondurables is more narrow than that in the National Income and Product Accounts. More exactly, we exclude clothing and footwear from nondurables. To the extent there is measurement error in a household's response for c_j, as allowed for in (9), then an OLS estimate of θ_i will be biased toward zero. For this reason we instrument for $\widehat{c}_j$ as follows. For each household we separate spending on nondurables in the first and second interview quarters from those in the third and fourth interview quarters. We treat $\widehat{c}_j$ as nondurable consumption measured for the latter two quarters, then instrument for this consumption with the household's measured consumption in the first two interview quarters. Consistent with there being measurement error, the coefficient obtained by instrumenting is modestly higher for each good than the coefficient obtained with OLS.

Results for the quality Engel curves with estimation by two-stage least squares are presented in the first column of Table 4. Standard errors are in parentheses. The elasticities vary considerably. The steepest quality Engel curves are for jewelry, window coverings, rugs, and cars. A one percent increase in nondurable spending is associated with about a one percent increase in purchase price for these goods. At the other extreme, prices for microwave ovens, sewing machines, vacuums, and lawn and garden equipment each exhibit unit-price elasticities with respect to total nondurables of 0.25 or less.

We tested the stability of the quality slopes over time by adding a variable interacting $\ln c$ with a linear time trend. The coefficient on this trend term was not significantly different from

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our constructed instrumental variable. Such selection, if important, will also occur over time. As economy-wide income and consumption rise, the amount of quality-upgrading in the average purchase price of a good will, similar to the cross-section pattern with respect to c, be biased down by the entry into the markets of consumers with a relatively low preference for the good. Thus it is not clear whether one should employ selection-corrected or uncorrected estimates of θ_i in constructing the instrumental variable for quality growth.

zero at the .05 level for 57 of the 66 goods (two were significantly negative, seven were significantly positive). So typically we cannot reject stability of the quality slopes.

We also explored the appropriateness of the log-linear formulation. We compared our log-linear estimates to nonparametric (kernel) estimates, and found no distinct patterns of convexity or concavity, nor any distinct patterns of floors or ceilings.[15] Figures 3 and 4 illustrate by comparing the linear and nonparametric Engel curves for cars and vacuums, respectively. Cars are a high expenditure share good among those with the steepest quality slopes. Vacuums are a relatively high expenditure share good among those with the flattest quality slopes. The linear estimates track the nonparametric estimates quite well, especially over the (-.5, +.5) range containing 88% of the log consumption observations.

We next compare our quality slopes to the steepness of the overall Engel curve for each good. In the second column of Table 4 we report *quantity* Engel curves for each of the 66 goods. These are constructed as follows. For each good a household's quantity of purchases of the good is regressed on $\ln c$ as well as the time and household control variables employed in estimating the quality Engel curves. Again, nondurable consumption in quarters 3 and 4 is instrumented by consumption in quarters 1 and 2. The sample here, however, is the full sample of 65,189 households, not just those purchasing the good. So that the regression response in quantity can be interpreted as an elasticity, we first divide a household's purchase quantity of good i by the mean purchase quantity for good i in the sample. As Table 4 shows, the quantity Engel curves also differ sharply across goods. All goods display elasticities of at least .28. 14 goods display quantity Engel curves with elasticities greater than 1.

The final column of Table 4 presents the size of the quality Engel curve relative to the sum of responses in quality and quantity (i.e., relative to the overall Engel curve that incorporates how both quality and quantity increase as nondurable consumption rises). The share accounted

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[15] Specifically, for the kernel estimation we used the default in Eviews: an Epanechnikov kernel with bandwidth 0.15*(max $\ln c$ − min $\ln c$), local linear regression, linear binning, and 100 gridpoints. After estimation but before plotting, we trimmed the top and bottom 1% of the $\ln c$ observations.

for by the quality Engel curve ranges from a low of 23% for microwaves to a high of 74% for trucks. On average the quality response to consumption is actually more important in magnitude than the quantity response: when weighted by expenditures, the average share accounted for by the quality Engel curve is 56%. This means that, absent changes in the quality-adjusted prices of our 66 goods compared to nondurable consumption, we would expect 56% of rising real consumption of our durable goods to take the form of rising quality. We take this as supporting an important role for quality upgrading in models of growth.

5. Estimating Quality Changes

Quality Engel curves and unit-price inflation

We first ask if a good that exhibits a large unit price response to consumption cross-sectionally (a steep quality slope) also displays a faster increase in unit prices over time. The answer, it turns out, is yes. We then estimate to what extent these predictable, quality-induced variations in unit-price inflation contaminate BLS estimates of a good's price inflation.

There is a strong positive relation, as conjectured, between the magnitude of a good's quality Engel curve and its rate of unit-price inflation. The correlation equals 0.51, suggesting the quality slope is a highly relevant instrument. Figure 5 plots the rates of unit-price inflation against the quality slope for the sample of 66 goods. Microwave ovens is an outlier because of its very low rate of unit-price increase. A very strong positive relation remains, however, if we remove microwaves, with the correlation equaling 0.48.

Recall that equation (6) predicts a good's unit-price inflation rate should be higher the steeper its quality slope θ_i. In Table 5 we report results from Weighted Least Squares regressions (with the weights equaling December 1997 CPI shares). The dependent variable is average unit-price inflation over 1980-1996 for good *i*, and the independent variable is the quality slope estimated for good *i* from 1980-1996 cross-sections of the CEX. Hence there is one observation per consumer durable category, for 66 observations in the full sample. As shown in Row 1 of Table 5, the hypothesis that unit-price inflation is unrelated to θ_i is easily rejected with a t-statistic of 5.8. To check robustness we re-estimated after eliminating microwaves and trucks from the sample. These were the only goods with rates of unit-price inflation two or more standard deviations from the mean of –0.44% per year. Row 2 of Table 5 shows that, excluding these two goods, the coefficient on θ_i falls slightly from .0424 to .0413 and the t-statistic rises considerably to 12.1. We also re-estimated after eliminating jewelry, rugs, and window coverings from the sample (the goods exhibiting an estimate of θ_i two or more standard deviations from the mean value of 0.57). Row 3 shows that the resulting coefficient and t-statistic are virtually the same as with the full sample.

Since cars and trucks are outliers in terms of their CPI weight in the regressions, together receiving 48% of the weight (39% for cars, 9% for trucks), in Row 4 of Table 5 we report results omitting them. The results change modestly (coefficient .0321 vs. .0424 in the full sample, t-statistic 5.2 vs. 5.8), but they do not hinge on the vehicle categories and their large weighting. Running unweighted least squares on the full sample yields similar results: a coefficient of .0411 with a t-statistic of 4.7. Finally, one could argue that the apparel categories (16 of the 66, with 21% of the CPI weight) are not fully independent observations, so Row 5 uses only the 50 non-apparel categories. The coefficient is modestly lower than the baseline estimate (.0366 vs. .0424), and the t-statistic is lower in line with the smaller sample and coefficient (3.4 vs. 5.8), but the coefficient remains highly significant.

Could the coefficient from this regression (e.g., the .0424 baseline estimate) plausibly reflect consumers upgrading quality faster for goods with steeper quality slopes? From (6), we anticipate a coefficient on the quality slope equal to $(\Delta c - \sigma\Delta z)$.[16] Assuming no unmeasured quality change for nondurables, Δc equals 1.26% per year from 1981 to 1995.[17] Now, the BLS prices of our durables typically fell relative to the BLS price of nondurables. The BLS prices for our goods fell by 0.82% per year on average (weighting goods by their CPI shares). For illustration suppose that σ equals 1 (utility is logarithmic in nondurable consumption). Then $\Delta c - \sigma\Delta z$, the impact of the quality slope on inflation in unit prices, should equal .0208 ($=$ 1.26% $-$ (–0.82%)).

Note, however, that this discussion has assumed that there is no unmeasured quality growth for durables. To fill the gap between .0208 and the coefficient of .0424 in Table 5 would require unmeasured quality growth of 2.16% per year on average across our durable goods (if σ=1). This is in line with the degree of unmeasured quality we estimate for our goods below (2.2 to 2.4% per year).

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[16] This discussion assumes that θ_i is uncorrelated with both Δz_i and Δv_i . Orthogonality of θ_i and Δz_i is required for validity of θ_i as an instrument, but orthogonality of θ_i with Δv_i is not.

[17] Each percent of unmeasured quality growth in nondurables understates both Δc and Δz by one percent. So, for $\sigma = 1$, it has precisely offsetting effects on the two terms in $(\Delta c - \sigma\Delta z)$.

We also note that, by multiplying the coefficient in this regression by the average value of θ_i of 0.76, we arrive at an estimate of the average rate of quality upgrading for our goods in response to growth in consumption and falling quality-adjusted prices for these goods. For the coefficient of .0424, the average implied quality growth is 3.2% per year. Again, this is reasonably close to what we estimate below (3.7 to 3.8%).

Now, we are assuming that a good with a steep quality slope exhibits fast unit-price inflation because of higher than average growth in its quality. This good will also typically exhibit a steep overall (quantity plus quality) Engel curve; for this reason, the demand for resources to produce this good should be rising. If the industry exhibits constant returns to scale then this will not affect the price per unit of quality for the good. If returns to scale are not constant, however, then steepness of the overall Engel curve will affect the good's price per unit of quality. One test of our assumption of constant returns is to see how price responds to a good's quantity Engel curve (those we reported in Table 4), as a steep quantity Engel curve also predicts rising demand for the product over time. Repeating the first row regression, now including the good's quantity Engel curve, yields an insignificant coefficient on the quantity Engel curve of $-.0089$ (standard error .0066). The coefficient on the quality Engel curve falls, but remains highly significant at .0350 with a standard error of .0091 and t-statistic of 3.9.

We conclude that a good's quality slope robustly predicts its unit-price inflation rate. A 1% point steeper quality slope suggests roughly 4% faster unit-price inflation for the good.

Quality Engel curves and BLS-price inflation

We are now prepared to estimate the parameter μ, which is the share of quality growth which gets misdiagnosed as inflation. Our estimate of μ is identified by combining equations (5), (6), and (8) with conditions that the residual Δz_i be orthogonal to our instruments θ_i and $(\theta_i - \theta)\Delta z_i$. Estimation is by GMM; and the results appear in Table 6. We first estimate μ employing only the quality slope as an instrument (Row 1). We clearly reject the hypothesis that $\mu = 0$ (t-statistic 4.9). Moreover, the estimate of μ is sizable, equaling 0.618 with a standard error of 0.125. This means that BLS prices rise by 62% as much as do unit prices in response to quality-upgrading predicted by a good's quality slope. If the BLS quality adjustments averaging 1.46% per year across our goods miss 62% of quality growth, then true quality growth should be 3.8% per year $(= 1.46\%/(1 - .618))$.

Table 6, Row 2 presents results adding as an instrument the interaction between $(\theta_i - \theta)$ and Δz_i. The estimate of μ is modestly reduced to 0.601 with a standard error of 0.119 and a t-statistic of 5.0.[18] The implied average growth in quality across our 66 goods is then 3.7% $(= 1.46\%/(1 - .601))$. This exceeds the actual 1.46% BLS adjustment by 2.2% per year, implying that BLS inflation for our goods is biased upward by 2.2% per year.

How do our estimates of bias compare to other estimates in the literature? The Boskin Commission (1996) estimated quality bias of 0.6% per year for the overall CPI, but 1.0% per year for the consumer durable sub-component (our calculation from the breakdown in their Table 2). Gordon (1990) estimated that the BLS price index for consumer durables was overstated by at least 1.5% per year from 1947 to 1983, and at least 1.0% per year from 1973-1983. Gordon considered his estimates lower bounds for at least two reasons. First, Gordon stressed that BLS techniques also fail to account for improved quality from greater durability (e.g., of automobile tires) and increased energy efficiency (e.g., of appliances). Second, Gordon assumed zero bias in the consumer durables that he did not examine (about one half of expenditures on durables).

Our estimate of μ could be overstated if quality-adjusted price changes are positively correlated with our quality slopes. That is, if goods with steep quality Engel curves happen to have slower rates of cost-reducing technological progress, then their prices will be rising for a

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[18] Suppose we calculate Δx_i based on the periods BLS prices are available, rather than using the entire 1980 to 1996 period. Using this alternative measure of Δx_i to construct the instrument $(\theta_i - \theta)\Delta z_i$ has very little effect. The estimate of μ becomes .622 (standard error .122, t-statistic 5.1). Using this alternative measure in the first-stage regression (6), as well as in constructing the instrument $(\theta_i - \theta)\Delta z_i$, leads to a μ estimate of .657 (standard error .163, t-statistic 4.0).

16 of our 66 goods are types of clothing or shoes. But our estimates are not particularly sensitive to the inclusion of these goods. Dropping these 16 goods drops the estimate of μ to .562 (standard error .146, t-statistic 3.9).

Finally, we also tested whether the μ coefficient sytematically differs in size for those goods that the BLS implicitly makes a large quality adjustment. (That is, goods with a large value in the final column of Table 2.) We find no significant interaction.

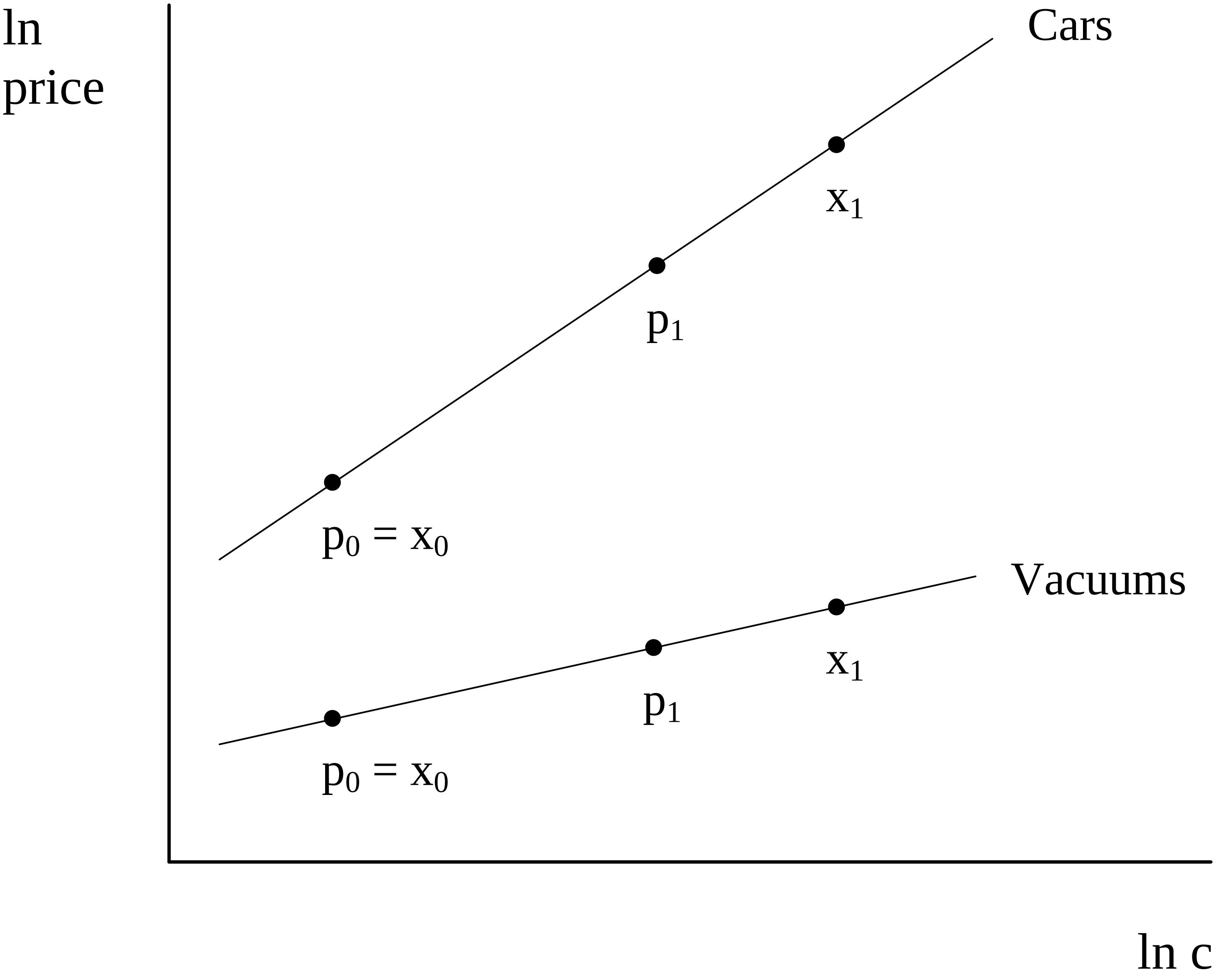
reason in addition to quality-upgrading. Put more simply, our identifying assumption in equation (7) may not hold. To address this possibility we re-estimated adding the change in the share of CEX households buying each good as a control variable. More households should be buying goods whose quality-adjusted relative price has fallen. Including this variable actually increases our estimate of μ slightly, from .601 to .612 (t-statistic still 5.0). Secondly, we re-estimated excluding goods with rates of BLS-price inflation more than two standard deviations away from the mean of –1.33% per year. This eliminated five goods from the sample (microwaves, TVs, radios, telephones, and luggage) and lowered the estimate of μ to .477 (standard error .104, t-statistic 4.6). This would imply inflation bias of 1.3% per year, versus the 2.4% implied by estimation of μ with the full sample of goods.

To summarize, differences in quality slopes successfully predict differences in unit-price inflation rates. Much of these differences pass through into differential rates of BLS-price inflation. Our preferred estimate of μ is about .60, which implies about 2.2% upward bias in BLS inflation for our consumer durables because of failure to fully net out quality growth. As a cautionary note, although we can reject the hypothesis of $\mu = 0$ with considerable confidence, our estimate of μ is associated with a nontrivial standard error. The two standard error bands contain .363 and .849. This translates into a fairly wide confidence interval in assigning a particular number to unmeasured quality growth. We can say, with greater confidence, that our estimates imply that at least one-third of quality upgrading was mismeasured as inflation, and that this generated a bias of at least 0.83% per year (the point estimate minus two standard errors, and the associated inflation bias).

6. Conclusion

We estimated quality Engel curves across 66 consumer durables from pooled cross-sections of households in the 1980 through 1996 U.S. Consumer Expenditure Surveys. We then used these to predict the speed of quality-upgrading for these goods. Just as if households were ascending their quality Engel curves over time, we found that the average price paid rose faster for goods with steeper quality Engel curves. BLS prices likewise increased more quickly for goods with steeper quality Engel curves, suggesting the BLS did not fully net out the impact of quality-upgrading on prices paid. We estimated quality growth of about 3.7% per year for our goods, with roughly 60% of this, or 2.2% per year, showing up as higher inflation rather than higher real growth. Even incorporating alternative samples and sampling error, our estimates imply that at least one-third of quality growth flows through into measured inflation, biasing consumer durables inflation upward by at least 0.80% per year.

Figure 1



p = BLS Price

x = Unit Price

$$\mu = \frac{(\Delta p_{cars} - \Delta p_{vacuums})}{(\Delta x_{cars} - \Delta x_{vacuums})}$$

Figure 2

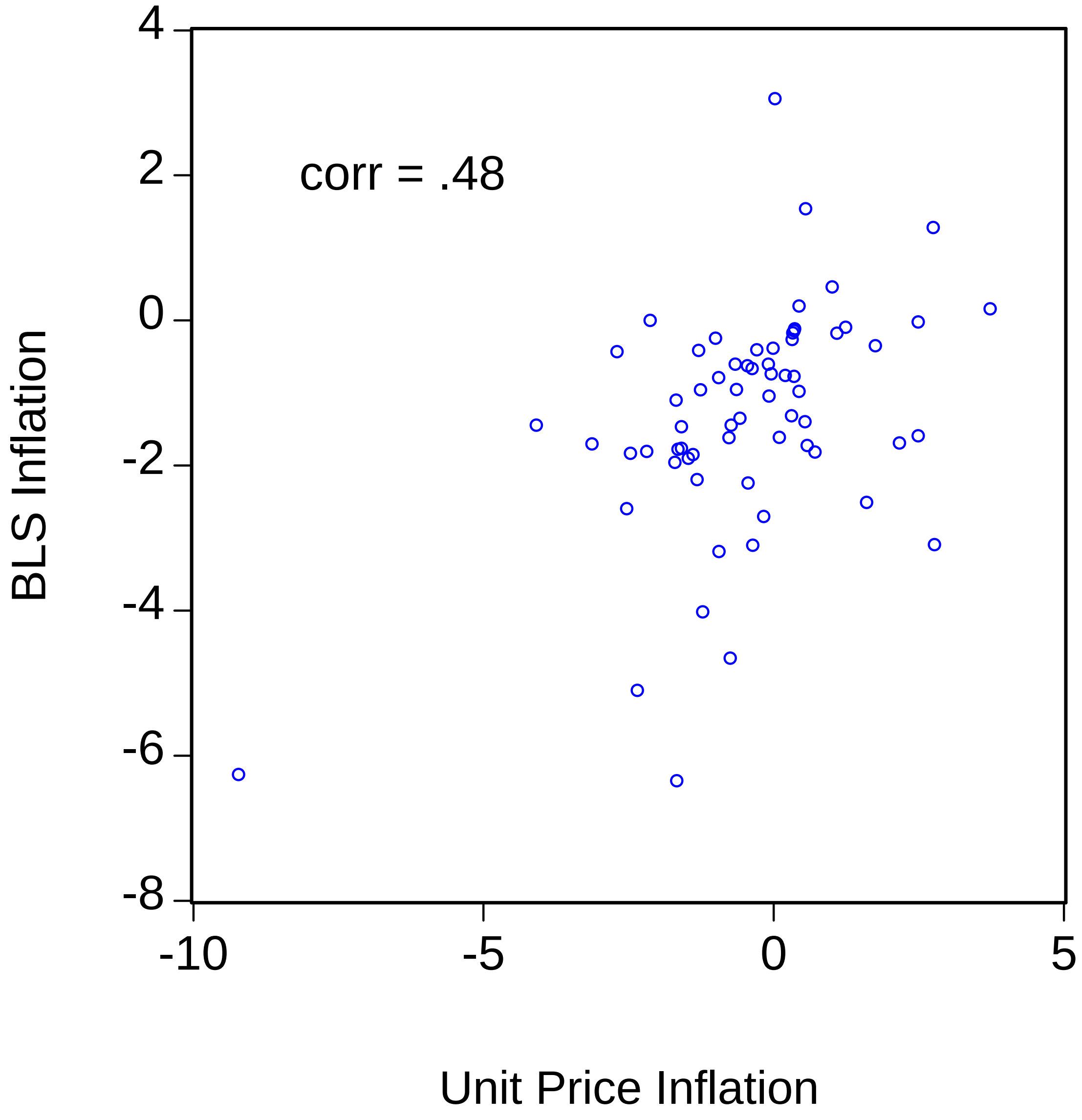


Figure 3

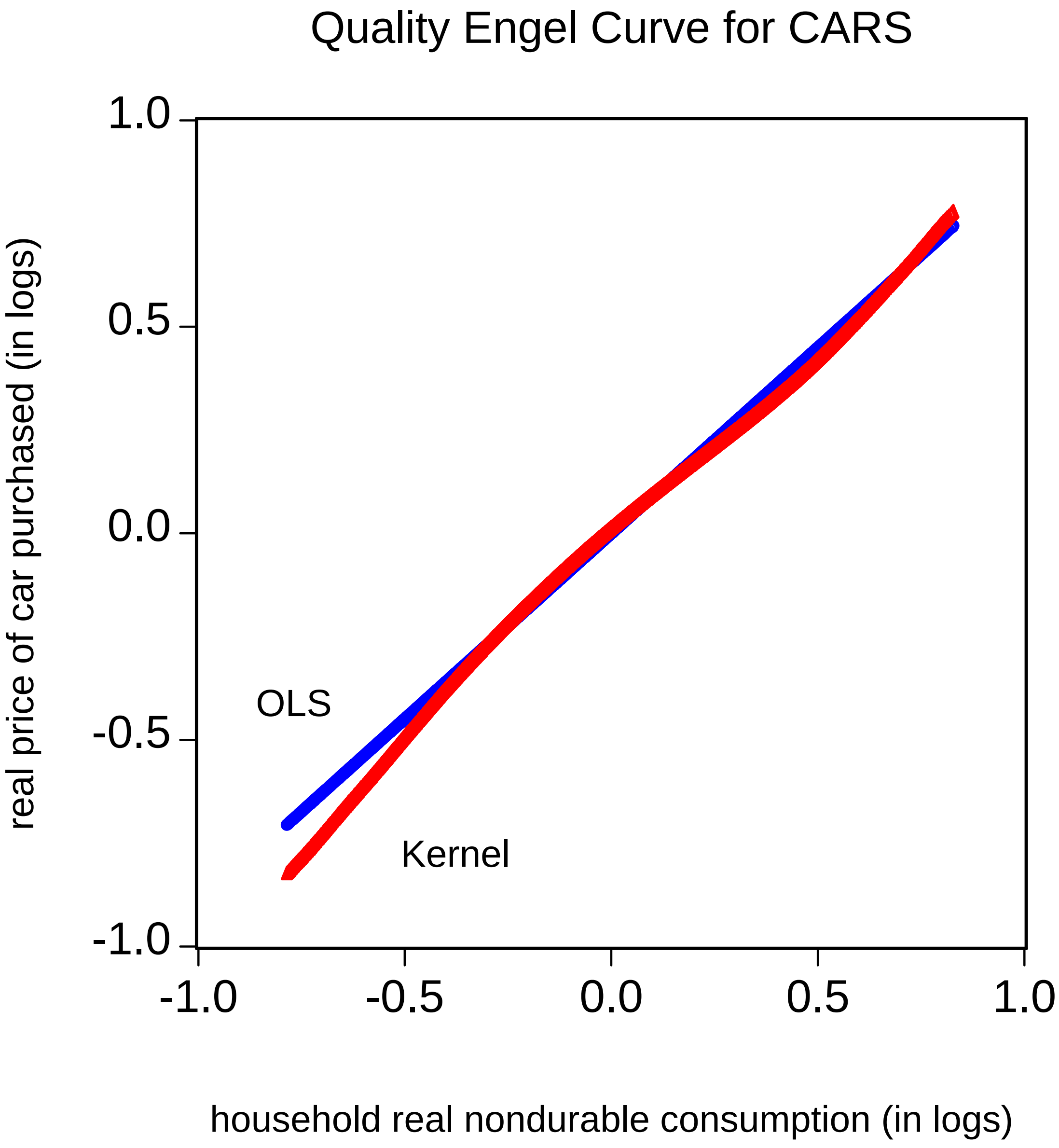

Quality Engel Curve for CARS
1.0
0.5
0.0
-0.5
-1.0
OLS
Kernel
-1.0
-0.5
0.0
0.5
1.0
real price of car purchased (in logs)
household real nondurable consumption (in logs)

Figure 4

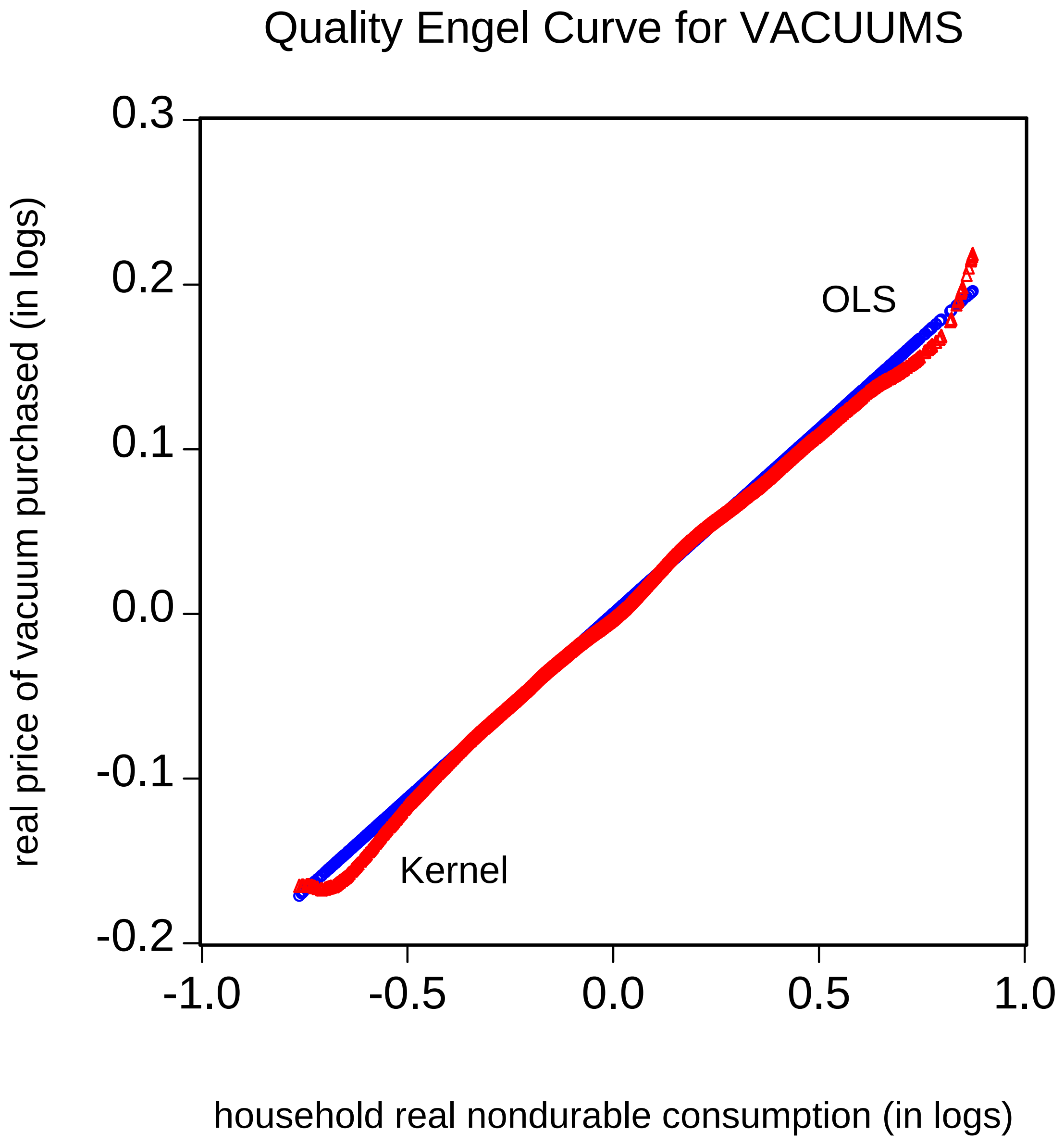

Quality Engel Curve for VACUUMS
0.3
0.2
0.1
0.0
-0.1
-0.2
real price of vacuum purchased (in logs)
OLS
Kernel
-1.0
-0.5
0.0
0.5
1.0
household real nondurable consumption (in logs)

Figure 5

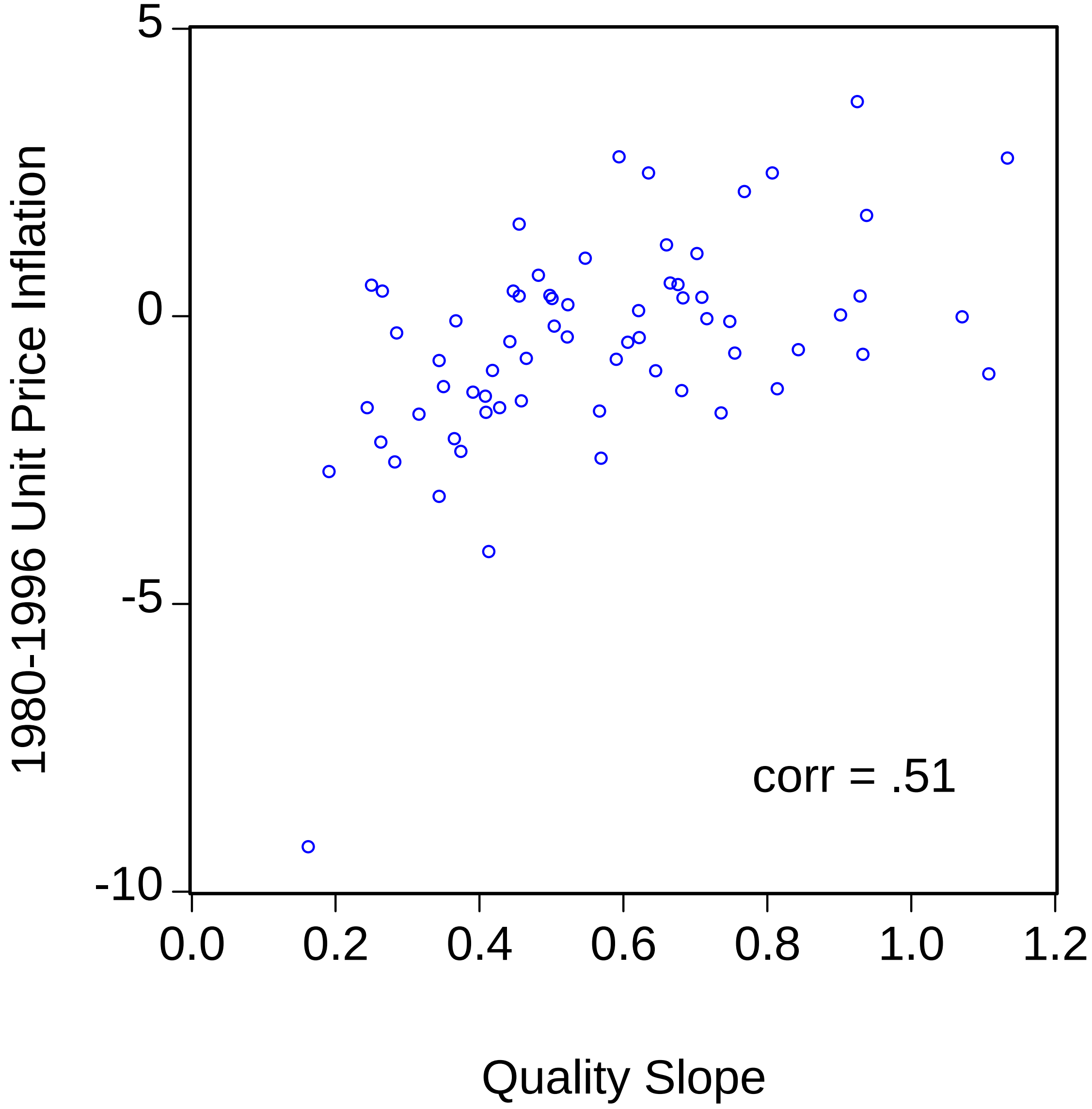

5
0
-5
-10
1980-1996 Unit Price Inflation
corr = .51
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Quality Slope

TABLE 1: Percent Buying Individual Consumer Goods

Good	(1) Number Buying	(2) Fraction Buying	(3) Fraction Buying 2+ (of those buying)
Carpeting	4835	7.4%	0%
Curtains and Drapes	9251	14.2	20.1
Mattress and Springs	5911	9.1	10.5
Bedroom Furniture	6649	10.2	17.2
Sofas	5347	8.2	8.4
Living Room Furniture	8731	13.4	30.5
Kitchen/Dining Room Furniture	5131	7.9	12.5
Baby Furniture and Equipment	4915	7.5	35.8
Outdoor Furniture	5731	8.8	14.2
Refrigerators and Freezers	4365	6.7	12.9
Clothes Washers	3205	4.9	10.3
Clothes Dryers	2235	3.4	11.4
Stoves and Ovens	2563	3.9	15.1
Microwave Ovens	3567	5.5	5.2
Window Air Conditioners	1435	2.2	5.1
Televisions	10,346	15.9	11.0
Radios	8224	12.6	15.2
Stereos	4953	7.6	12.7
Rugs	5757	8.8	15.6
Window Coverings	5256	8.1	14.2
Clocks	5218	8.0	11.3
Lamps and Lights	8695	13.3	18.9
Telephones**	9379	14.4	18.6
Lawn and Garden Equipment	8112	12.4	20.0
Power Tools	6247	9.6	25.6
Vacuums	5045	7.7	8.7
Sewing Machines	1202	1.8	4.4
Small Kitchen Appliances	20,270	31.1	33.6
Heaters	6530	10.0	12.0
Hard Flooring	1088	1.7	33.8
Office Furniture	2311	3.5	13.8
Hand Tools	10,298	15.8	34.5
Men’s Suits	8663	13.3	23.1
Men’s Coats and Sportscoats	18,837	28.9	35.9
Men’s and Boys’ Sleepwear	9592	14.7	28.9
Men’s and Boys’ Sweaters	18,378	28.2	40.3
Men’s Pants	34,812	53.4	55.8
Boys’ Coats, Suits, and Sportscoats	9124	14.0	44.0
Women’s and Girls’ Coats	27,068	41.5	47.1
Women’s and Girls’ Dresses	34,502	52.9	57.9
Women’s Sweaters and Vests	26,358	40.4	48.9
Women’s Skirts and Pants	38,565	59.2	65.3
Women and Girls’ Sportswear	21,695	33.3	48.4
Women’s Sleepwear	22,475	34.5	41.0
Women’s Suits	11,373	17.4	29.9

TABLE 1: Percent Buying Individual Consumer Goods (continued)

Good	(1) Number Buying	(2) Fraction Buying	(3) Fraction Buying 2+ (of those buying)
Men's Footwear	30,682	47.1	47.5
Boys' and Girls' Footwear	20,525	31.5	76.6
Women's Footwear	41,274	63.3	62.8
Watches	17,489	26.8	26.1
Jewelry	25,439	39.0	55.5
Luggage	6614	10.1	19.4
Cars	13,483	20.7	13.5
Trucks	4489	6.9	7.2
Tires	25,597	39.3	34.7
Eyeglasses and Contacts	18,901	29.0	32.6
Sports & Exercise Equipment	16,989	26.1	47.3
Bicycles	5401	8.3	19.5
Camping Equipment	3237	5.0	28.9
Fishing and Hunting Equipment	6903	10.6	45.4
Winter/Water Sports Equipment	6523	10.0	34.5
Playground Equipment	1263	1.9	10.5
Musical Instruments	4814	7.4	36.5
Photographic Equipment	6665	10.2	17.3
Personal Care Appliances	10,389	15.9	25.3
Calculators*	4625	7.1	11.3
Typewriters**	1610	2.5	5.6
Mean	11,321	17.4	26.3
Median	6784	10.4	20.1
Standard deviation	9911	15.2	17.3
Maximum	41,274	63.3	76.6
Minimum	1088	1.7	0.0

SAMPLE: Cross-sections of households in the 1980-1996 U.S. Consumer Expenditure Surveys.

* 1982-1996. The 1980 and 1981 Consumer Expenditure Surveys did not include this item.
** 1983-1996. The 1980, 1981, and 1982 Surveys did not include this item.

OBSERVATIONS: 65,189 household-years.

Fraction Buying = % of households buying 1 or more of the good in a 12 month span.

Fraction Buying 2+ (of those buying) = % of buying households who buy more than 1 in a 12 month span.

TABLE 2: Changes in Unit Prices vs. BLS Prices

Good	(1) 1980-1996 Annual % Change in Unit Prices	(2) Subperiod Annual % Change in Unit Prices	(3) Subperiod Annual % Change in BLS Prices	(4) Column (2) – Column (3) (= Implied BLS Quality Change)
Carpeting	2.17%	2.17%	-1.69%	3.86%
Curtains and Drapes	0.35	0.35	-0.06	0.41
Mattress and Springs	-0.37	-0.37	-0.36	0.29
Bedroom Furniture	1.09	1.09	-0.17	1.26
Sofas	-0.64	-0.64	-0.95	0.31
Living Room Furniture	-0.09	-0.09	-0.60	0.51
Kitchen/Dining Room Furniture	-0.58	-0.58	-1.53	0.76
Baby Furniture and Equipment	1.60	1.60	-2.51	4.10
Outdoor Furniture	-0.66	-0.66	-0.60	-0.06
Refrigerators and Freezers	-1.47	-1.47	-1.90	0.43
Clothes Washers	-2.53	-2.53	-2.60	0.07
Clothes Dryers	-1.70	-1.70	-1.96	0.26
Stoves and Ovens	-1.39	-1.08	-1.85	0.77
Microwave Ovens	-9.22	-7.81	-6.26	-1.55
Window Air Conditioners	-2.19	-0.48	-1.81	1.32
Televisions	-1.67	-1.67	-6.35	4.68
Radios	-2.35	-2.35	-4.62	2.27
Stereos	-3.13	-3.13	-1.70	-1.43
Rugs	-0.01	-1.06	-0.38	-0.68
Window Coverings	-1.00	-1.00	-0.24	-0.75
Clocks	-1.68	0.33	-1.10	1.43
Lamps and Lights	-1.26	-1.26	-0.95	-0.30
Telephones	-0.75	1.03	-4.66	5.69
Lawn and Garden Equipment	0.54	0.54	-1.40	1.94
Power Tools	-0.29	-0.29	-0.40	0.11
Vacuums	-1.59	-1.59	-1.46	-0.12
Sewing Machines	-2.70	0.21	-0.43	0.64
Small Kitchen Appliances	-1.32	-0.84	-2.19	1.35
Heaters	-4.09	-2.04	-1.44	-0.60
Hard Flooring	2.49	2.49	-0.02	2.52
Office Furniture	0.33	-1.59	-0.17	-1.42
Hand Tools	1.01	-0.12	0.46	-0.58
Men's Suits	0.32	0.32	-0.26	0.58
Men's Coats and Sportscoats	-0.45	-0.45	-0.63	0.18
Men's and Boys' Sleepwear	-0.08	-0.08	-1.04	0.96
Men's and Boys' Sweaters	0.35	-0.14	-0.77	0.63
Men's Pants	0.44	0.44	-0.98	1.41
Boys' Coats, Suits, and Sportscoats	0.71	0.71	-1.81	2.53
Women's and Girls' Coats	-1.65	-1.65	-1.77	0.12
Women's and Girls' Dresses	0.58	0.58	-1.73	2.30
Women's Sweaters and Vests	-0.17	-0.92	-2.70	1.78
Women's Skirts and Pants	-0.36	-0.37	-3.10	2.73
Women and Girls' Sportswear	-0.73	-0.73	-1.44	0.71
Women's Sleepwear	-0.44	-0.70	-2.24	1.54
Women's Suits	-0.04	-0.04	-0.74	0.69

TABLE 2: Changes in Unit Prices vs. BLS Prices (continued)

Good	(1) 1980-1996 Annual % Change in Unit Prices	(2) Subperiod Annual % Change in Unit Prices	(3) Subperiod Annual % Change in BLS Prices	(4) Column (2) – Column (3) (= Implied BLS Quality Change)
Men's Footwear	0.20%	0.20%	-0.76%	0.96%
Boys' and Girls' Footwear	0.31	0.31	-1.32	1.63
Women's Footwear	0.10	0.10	-1.61	1.71
Watches	-1.29	-0.68	-0.41	-0.27
Jewelry	2.75	1.58	1.28	0.30
Luggage	0.02	0.19	3.06	-2.86
Cars	1.75	1.75	-0.35	2.10
Trucks	3.73	0.83	0.16	0.67
Tires	-0.94	-0.94	-3.19	2.25
Eyeglasses and Contacts	0.44	-0.49	0.20	-0.69
Sports & Exercise Equipment	2.77	2.36	-3.09	5.46
Bicycles	-1.59	-1.59	-1.76	0.17
Camping Equipment	0.36	0.47	-0.12	0.59
Fishing and Hunting Equipment	1.24	1.23	-0.09	1.32
Winter/Water Sports Equipment	2.49	2.49	-1.59	4.08
Playground Equipment	0.55	-1.36	1.54	-2.90
Musical Instruments	-2.13	-2.13	0.00	-2.12
Photographic Equipment	-0.95	-0.95	-0.79	-0.16
Personal Care Appliances	-0.77	-0.77	-1.62	0.85
Calculators	-1.22	0.28	-4.02	4.30
Typewriters	-2.47	-0.77	-1.83	1.06
Mean	-0.44	-.39	-1.33	0.94
Median	-0.36	-.41	-1.21	0.68
Standard deviation	1.86	1.53	1.57	1.74
Maximum	3.73	2.49	3.06	5.69
Minimum	-9.22	-7.81	-6.35	-2.90
Weighted Mean	0.97	0.64	-0.82	1.46

The "unit price" is the average of all purchases made in each year across households. The unit prices for the 66 goods are based on 1,469,561 price observations. The period is 1982-1996 for calculators, and 1983-1996 for telephones and typewriters.

The Weighted Mean is calculated using the CPI shares in 1997.

Subperiods are because the following years were not covered by the BLS price series:

1980-81: Stoves and ovens; microwave ovens.
1980-82: Window air conditioners; small kitchen appliances; heaters; hand tools; womens' skirts and pants; womens' sleepwear; girls' coats and jackets.
1980-83: Rugs; clocks; mens' and boys' sweaters; womens' sweaters and vests; trucks.
1980-84: Luggage; sports and exercise equipment; playground equipment.
1980-85: Telephones; hunting and fishing equipment; calculators; typewriters.
1980-86: Watches; jewelry; eyeglasses and contacts.
1990-96: Sewing machines. 1992-96: Camping equipment. 1993-96: Microwave ovens.

TABLE 3: BLS Item Substitutions and Methods of Quality Adjustment, 1997

Good	(1) Weight in December 1997 CPI	(2) Item Substitution Rate	(3) % of Substitutions “Comparable”	(4) % “Direct” Quality Adjustments	(5) % “Linked” to inflation of other items
Carpeting	.021%	11.8%	0%	11%	89%
Curtains and Drapes	.052	6.5	57	0	43
Mattress and Springs	.158	6.9	49	0	51
Other Bedroom Furniture	.203	6.3	36	0	64
Sofas	.225	7.7	50	0	50
Living Room Tables	.179	4.5	33	0	67
Kitchen/Dining Room Furniture	.146	7.0	32	0	68
Baby Furniture and Equipment	.044	8.0	62	0	38
Outdoor Furniture	.025	19.4	62	0	38
Refrigerators and Freezers	.084	9.6	91	0	9
Clothes Washers	.057	8.5	100	0	0
Clothes Dryers	.035	5.4	94	0	6
Stoves and Ovens	.038	9.5	89	0	11
Microwave Ovens	.043	12.2	93	0	8
Window Air Conditioners	.015	5.3	75	0	25
Televisions	.128	14.1	62	0	37
Radios	.023	14.7	42	0	58
Stereos	.075	15.4	41	0	59
Rugs	.062	7.0	58	3	39
Window Coverings	.060	2.5	77	0	23
Clocks	.011	11.3	44	0	56
Lamps and Lights	.049	10.5	62	0	38
Telephones	.012	4.8	33	0	67
Lawn and Garden Equipment	.085	9.8	86	1	13
Power Tools	.035	3.2	64	0	36
Vacuums, Sewing Machines *	.042	10.6	76	2	22
Small Kitchen Appliances, Heaters *	.072	8.0	56	0	44
Hard Flooring	.007	2.9	25	0	75
Office Furniture	.122	7.4	31	0	69
Hand Tools	.026	3.7	56	0	44
Men’s Suits	.193	4.7	51	39	9
Men’s Coats and Sportscoats	.119	12.0	67	11	22
Men’s and Boys’ Sleepwear	.044	5.9	94	0	6
Men’s and Boys’ Sweaters	.043	20.2	54	16	30
Men’s Pants	.212	5.4	79	11	10
Boys’ Coats, Suits, and Sportscoats	.035	22.0	76	0	24
Women’s and Girls’ Coats	.192	26.3	56	18	27
Women’s and Girls’ Dresses	.284	38.3	56	21	23
Women’s Sweaters and Vests	.072	27.7	61	20	19
Women’s Skirts and Pants	.394	14.4	63	21	16
Women’s and Girls’ Sportswear	.086	29.1	75	7	19
Women’s Sleepwear	.068	24.9	82	0	18
Women’s Suits	.168	32.4	57	23	20

TABLE 3: BLS Item Substitutions and Methods of Quality Adjustment (continued)

Good	(1) Weight in December 1997 CPI	(2) Item Substitution Rate	(3) % of Substitutions "Comparable"	(4) % "Direct" Quality Adjustments	(5) % "Linked" to inflation of other items
Men's Footwear	.224%	7.9%	82%	4%	14%
Boys' and Girls' Footwear	.154	15.1	83	0	17
Women's Footwear	.341	11.4	79	3	18
Watches	.078	8.7	77	0	23
Jewelry	.323	7.5	66	3	31
Luggage	.035	10.9	60	0	40
Cars	4.811	16.5	30	35	35
Trucks	1.120	15.6	23	50	26
Tires	.256	2.5	83	0	17
Eyeglasses and Contacts	.335	2.9	50	13	37
Sports and Exercise Equipment	.210	8.1	47	2	51
Bicycles	.181	10.3	78	0	22
Camping, Fishing, Hunting Equip.*	.046	7.5	55	2	43
Winter/Water Sports Equipment	.163	8.3	45	2	53
Playground Equipment	.001	37.5	0	0	100
Musical Instruments	.062	5.3	56	4	41
Photographic Equipment	.048	7.0	74	0	26
Personal Care Appliances	.011	8.9	71	0	29
Calculators, Typewriters *	.004	2.4	100	0	0
Mean		11.2	61	5	34
Median		8.4	61	0	30
Standard Deviation		8.2	22	10	22
Maximum		38.3	100	50	100
Minimum		2.4	0	0	0
Weighted Mean		13.8	46	22	32
ALL Price Quotes in the CPI		3.8	48	27	25
Non-Residential Price Quotes		3.3	58	13	29
Non-Residential, Non-Vehicle		3.0	63	8	29

* Four pairs of categories had to be combined due to lack of finer BLS data.

Item Substitution Rate = fraction of price quotes for which a substitute replaced the previous month's item. (Since these are monthly, the fraction of items with some replacement during the year is much higher.)

"Comparable" substitutions: the replacement item is treated as the same as the previous month's item for pricing purposes. Thus no quality adjustment is made.

"Direct" quality adjustments: the price of the replacement item is divided by a measure of its quality relative to the previous month's item. Quality is measured using hedonics or the manufacturer's estimate of the cost of producing the replacement item relative to the previous item (gross of a markup).

The "Link" Method: the price of the replacement item is multiplied by the gross inflation rate of other items in the same category and divided by the ratio of its price to the price of the previous month's item.

TABLE 4: Engel Curve Slopes

Good	(1) Quality	(2) Quantity	(3) Quality/ (Quality + Quantity)
Carpeting	.77 (.08)	.60 (.04)	56%
Curtains and Drapes	.93 (.04)	.39 (.03)	70
Mattress and Springs	.62 (.04)	.65 (.04)	49
Bedroom Furniture	.70 (.05)	.75 (.04)	48
Sofas	.76 (.04)	.53 (.04)	59
Living Room Furniture	.75 (.04)	.63 (.03)	54
Kitchen/Dining Room Furniture	.84 (.06)	.67 (.04)	56
Baby Furniture and Equipment	.46 (.04)	.45 (.05)	50
Outdoor Furniture	.93 (.05)	1.00 (.04)	48
Refrigerators and Freezers	.46 (.04)	.35 (.04)	57
Clothes Washers	.28 (.04)	.37 (.05)	43
Clothes Dryers	.32 (.05)	.67 (.06)	32
Stoves and Ovens	.41 (.06)	.48 (.06)	46
Microwave Ovens	.16 (.03)	.53 (.05)	23
Window Air Conditioners	.26 (.08)	.31 (.07)	46
Televisions	.41 (.03)	.50 (.03)	45
Radios	.37 (.03)	.65 (.03)	37
Stereos	.34 (.04)	1.05 (.04)	25
Rugs	1.07 (.05)	.85 (.04)	56
Window Coverings	1.11 (.06)	.56 (.04)	66
Clocks	.74 (.04)	.50 (.04)	60
Lamps and Lights	.81 (.04)	.80 (.03)	50
Telephones	.59 (.03)	.73 (.03)	45
Lawn and Garden Equipment	.25 (.05)	.57 (.03)	30
Power Tools	.29 (.04)	.60 (.04)	32
Vacuums	.24 (.04)	.75 (.04)	25
Sewing Machines	.19 (.10)	.36 (.08)	35
Small Kitchen Appliances	.39 (.02)	.65 (.02)	38
Heaters	.41 (.03)	.28 (.04)	60
Hard Flooring	.64 (.15)	.30 (.11)	68
Office Furniture	.71 (.07)	1.11 (.06)	39
Hand Tools	.55 (.03)	.58 (.03)	49
Men’s Suits	.68 (.02)	1.52 (.03)	31
Men’s Coats and Sportscoats	.61 (.02)	1.24 (.02)	33
Men’s and Boys’ Sleepwear	.37 (.02)	.97 (.03)	27
Men’s and Boys’ Sweaters	.46 (.01)	1.13 (.02)	29
Men’s Pants	.45 (.01)	.71 (.01)	39
Boys’ Coats, Suits, and Sportscoats	.48 (.02)	.68 (.03)	41
Women’s and Girls’ Coats	.57 (.01)	1.08 (.02)	34
Women’s and Girls’ Dresses	.67 (.01)	.96 (.01)	41
Women’s Sweaters and Vests	.50 (.01)	1.11 (.02)	31
Women’s Skirts and Pants	.52 (.01)	.89 (.01)	37
Women and Girls’ Sportswear	.47 (.01)	1.28 (.02)	27
Women’s Sleepwear	.44 (.01)	.97 (.02)	31
Women’s Suits	.72 (.02)	1.44 (.03)	33

TABLE 4: Engel Curve Slopes (continued)

Good	(1) Quality	(2) Quantity	(3) Quality/ (Quality + Quantity)
Men's Footwear	.52 (.01)	.57 (.01)	48%
Boys' and Girls' Footwear	.50 (.01)	.43 (.02)	54
Women's Footwear	.62 (.01)	.70 (.01)	47
Watches	.68 (.02)	.70 (.02)	49
Jewelry	1.13 (.02)	1.06 (.02)	52
Luggage	.90 (.04)	1.54 (.04)	37
Cars	.94 (.03)	.39 (.02)	71
Trucks	.93 (.06)	.33 (.04)	74
Tires	.42 (.02)	.67 (.02)	38
Eyeglasses and Contacts	.27 (.02)	.75 (.02)	26
Sports & Exercise Equipment	.59 (.03)	1.30 (.03)	31
Bicycles	.43 (.05)	.67 (.04)	39
Camping Equipment	.50 (.06)	.95 (.06)	34
Fishing and Hunting Equipment	.66 (.04)	.59 (.04)	53
Winter/Water Sports Equipment	.81 (.05)	1.45 (.04)	36
Playground Equipment	.68 (.13)	.71 (.08)	49
Musical Instruments	.37 (.07)	.90 (.05)	29
Photographic Equipment	.65 (.04)	.97 (.04)	40
Personal Care Appliances	.34 (.02)	.90 (.03)	28
Calculators	.35 (.04)	.81 (.04)	30
Typewriters	.57 (.09)	.68 (.07)	46
Mean	.57	.76	43
Median	.54	.69	41
Standard deviation	.23	.31	13
Maximum	1.13	1.54	74
Minimum	.16	.28	23
Weighted Mean	.76	.62	56

SAMPLE: Cross-sections of households in the 1980-1996 U.S. Consumer Expenditure Surveys. (1982-1996 for calculators, and 1983-96 for telephones and typewriters.)

OBSERVATIONS: 65,189 household-years for the Quantity regressions. For the Quality regressions, observations are household-years with purchases of the good. Thus the number of observations varies by good for the Quality regressions. See Table 1 for the number of observations for each good.

The Weighted Mean is calculated using the CPI shares in December 1997.

Across the 66 goods in the table, the correlation between the Quality and Quantity slopes is 0.20.

TABLE 5: Predicting Changes in Unit Prices

Regressor ➔ **WLS Regressions ⬇**	q_i (Quality Slope)	**Adj. R^2**	**# of observations**
Full sample of goods	.0424 (.0072) t = 5.8	.93	66
Minus 2+ SD D$\mathbf{Lnx_i}$ extremes (Excludes microwave ovens and trucks)	.0413 (.0034) t = 12.1	.98	64
Minus 2+ SD q_i extremes (Excludes jewelry, rugs, and window coverings)	.0425 (.0075) t = 5.7	.93	64
Minus CPI Weight extremes (Excludes cars and trucks)	.0321 (.0062) t = 5.2	.31	64
Minus Apparel (Excludes the 16 clothes and shoes categories)	.0366 (.0106) t = 3.4	.93	50

TABLE 6: Estimates of m, Quality Growth, and Inflation Bias

Instrument Set ↓	m	**Average Quality Growth**	**Upwards Inflation Bias**	**Adj. R^2**
q_i	.618 (.125) t = 4.9	3.8%	2.4%	.56
q_i, $(q_i - q)D\mathbf{z}_i$	.601 (.119) t = 5.0	3.7%	2.2%	.57

# of observations = 66.

μ = the fraction of quality growth that shows up as inflation in the BLS price deflators.

θ_i = the quality slope for good *i*.

Δz_i = the growth rate of the quality-adjusted relative price of good *i* (relative to the price of nondurable consumption).

ESTIMATION METHOD:
The estimating equation is $\Delta p_i = \mu \cdot \Delta x_i + (1-\mu) \cdot \Delta z_i$. (This is equation (5) in the text.) Here μ is estimated by GMM using the instruments listed above. That is, μ is estimated by exploiting the orthogonality of Δz_i to the instruments given.

AVERAGE QUALITY GROWTH:
The difference between the unit price inflation rates Δx_i and the BLS inflation rates Δp_i is an estimate of the BLS's quality adjustments. Across our 66 goods, these quality adjustments averaged 1.46% per year (when the goods are weighted by their 1997 CPI share). Thus if the BLS adjustments are capturing only $(1-\mu)$ of total quality growth, total quality growth must be $1.46/(1-\mu)$.

UPWARDS INFLATION BIAS:
The BLS misses the fraction μ of total quality growth, which equals $1.46 \cdot \mu/(1-\mu)$.

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