Quantifying Quality Growth

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Using U.S. Consumer Expenditure Surveys, we estimate "quality Engel curves" for 66 durable goods based on the extent richer households pay more for each good. The same data show that the average price paid rises faster from 1980 to 1996 for goods with steeper quality Engel curves, as if households are ascending these curves. BLS prices likewise increase more quickly for goods with steeper quality Engel curves, suggesting the BLS does not fully net out the impact of quality upgrading. We estimate that annual quality growth averages 3.7 percent for our goods, with 2.2 percent showing up as higher inflation. (*JEL* D12, O40, E31)

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 Irma Adelman and Zvi Griliches (1961) and Griliches (1961) have been applied to only a limited number of goods (e.g., cars, houses, computers). Matthew D. Shapiro and David W. Wilcox (1996 p. 124) describe the measurement of quality change as necessitating "house-to-house combat," that is, detailed good-by-good studies. The Boskin Commission Report (Michael J. Boskin et al., 1996) cites only a handful of studies in arriving at its estimate that unmeasured quality change biases U.S. Consumer Price Index (CPI) inflation upward by 0.6 percent per year.[1]

We introduce an instrumental variables (IV) approach to estimate the rate of unmeasured quality growth for 66 durable consumer goods that constitute over 80 percent of U.S. spending on consumer durables. Our instrument is based on predicting which of these 66 goods will display relatively rapid quality growth, then contrasting how unit prices versus government-measured prices respond to these differences in quality growth. Inflation in a good's unit price reflects growth in the average quality of the good as well as its true rate of price inflation. Ideally, the U.S. Bureau of Labor Statistics (BLS) fully controls for quality changes, producing measures of inflation equal to the true rates of inflation. But suppose BLS procedures do not fully control for quality changes, with part of quality-driven price increases inadvertently recorded as price inflation. Then BLS inflation rates, like unit price inflation rates, will predictably respond to quality increases. In turn, the extent of quality growth that escapes BLS measurement can be identified by comparing the magnitude of responses in BLS and unit prices to predictable differences in quality growth.

To predict those consumer durables that will display more rapid quality growth we exploit "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

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[1] Including studies on new goods as well as higher quality goods, the Boskin Commission cites William C. Randolph (1988) on housing, Robert J. Gordon on durable goods (1990), Manuel Trajtenberg (1990) on medical imaging devices, Griliches and Iain Cockburn (1994) on prescription drugs, Steven Berry et al. (1996) on new cars, David M. Cutler et al. (1996) on heart attack treatment, Jerry A. Hausman on breakfast cereal (1997) and cell phones (1999), and William D. Nordhaus (1997) on lighting.

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 do tend to buy more expensive goods, so the estimated slopes are all positive and significant. Averaging across the goods, the quality portion comprises 56 percent of the overall Engel curve, suggesting an 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 do, 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 quality Engel curves do not display systematically faster or slower true inflation over time, a good's *relative* quality Engel curve provides a valid instrument for quality-driven growth in unit prices.

We find that our estimated quality Engel curve slopes are highly correlated with unit price changes for the 66 goods (correlation coefficient of 0.51). 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 percent per year on average for the 66 goods. This quality growth can take several forms. One form is rising market share of existing, above-average-quality goods. Another is the replacement of existing goods in the market with higher-quality versions. As we discuss below, our methodology can in principle capture both types of quality upgrading.

Because the 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. 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 percent 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 percent per year for our 66 goods.

We can briefly summarize our strategy as follows. The data we use have three dimensions of variation: goods, households, and time. For each good, we identify its quality Engel curve by regressing the unit price paid by the household on the household's spending on nondurable goods. We then identify the fraction of quality upgrading missed by the BLS by regressing, for the sample of 66 goods, the time-average of BLS inflation on the time-average of unit price inflation, instrumenting for the latter with each good's quality Engel curve slope.

The rest of the paper proceeds as follows. In Section I 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 II we present the time-series behavior of unit price and BLS price inflation rates for our 66 goods. In Section III we estimate quality slopes for the 66 goods using household data. In Section IV 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 V concludes.

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

The typical model of quality improvements [see, e.g., Philippe Aghion and Peter Howitt (1992)] focuses on firm incentives to design higher-quality goods. The preference side of the

[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.

model is usually kept simple, with consumers preferring higher quality but substituting 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 that 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.

A. *Household Quality Choices*

At time 0, household h maximizes lifetime utility given by

$$U_{h0} = \sum_{t=0}^{\infty} \beta^t u_{ht},$$

where β is the discount factor. u_{ht} is utility derived during period t:

$$u_{ht} = \frac{c_{ht}^{1-1/\sigma} - 1}{1 - 1/\sigma} + \sum_{i=1}^{N} \begin{cases} \tilde{\nu}_{iht} \dfrac{[q_{iht}^{1-1/\sigma_i} - 1]}{1 - 1/\sigma_i} & \text{if } q_{iht} > 0 \\ 0 & \text{if } q_{iht} = 0. \end{cases}$$

Each household chooses q_{iht}, the quality of good i, for N different durable, indivisible goods. A household may choose not to own durable good i at time t, in which case $q_{iht} = 0$.[3] Household h also buys an effective amount (quality times quantity) c_{ht} of the divisible, composite nondurable good. We separate out indivisible 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. $\tilde{\nu}_{iht}$ captures household h's taste for good i at time t. The parameters σ_i and σ govern the curvature of utility for the goods, and we assume $\sigma > 0$ and $\sigma_i > 0 \; \forall \; i$.

We abstract from uncertainty, allowing for a constant growth rate of real expenditures. We assume 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

$$c_{ht} + \sum_{i=1}^{N} \Omega_{iht} x_{iht} = y_{ht}, \tag{1}$$

where

$$x_{iht} = z_{it} q_{iht}. \tag{2}$$

In (1) the price of nondurable consumption is normalized to one and y is household expenditure, which equals income minus the change in assets. Ω_{iht} is 1 if household h purchases durable i in period t, and 0 otherwise. x_{iht} is the *unit price* paid by household h for good i in period t. As shown in (2), the unit price is the product of the common *quality-adjusted price* of good i facing all households at time t (z_{it}) and the *quality* of good i bought by household h at time t (q_{iht}). This captures the idea that, for a given type of product i (say televisions), the household faces a menu of quality–price combinations from which to choose. The menu slopes upward, so that higher-quality versions are more expensive.[4] We assume that the relative

[3] Subtracting 1 inside the brackets means utility from the good is positive only if $q_{iht} > 1$; that is, 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. This functional form also allows utility to be positive even when $\sigma_i < 1$, given $q_{iht} > 1$.

[4] In (2) 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 reflect either diminishing utility flow from quality because $\sigma_i < \infty$, or a rising price of quality from $\phi_i > 1$.

price of differing qualities of a good are determined by relative production costs, given competitive pricing. Moreover, this rate of transformation between lower- and higher-quality versions is unaffected by relative or total quantities produced. [Sherwin Rosen (1974) considers somewhat more general assumptions.]

Facing the quality–price menu, each household chooses whether to buy a good and, if so, what quality level to buy. We focus on the latter decision, 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:

$$\frac{\tilde{\nu}_{iht} q_{iht}^{-1/\sigma_i}\left(\dfrac{1-\beta^{\tau_i}}{1-\beta}\right)}{c_{ht}^{-1/\sigma}} = z_{it}. \tag{3}$$

Rearranging and taking natural logs yields

$$\ln q_{iht} = \theta_i \ln c_{ht} - \sigma\theta_i \ln z_{it} + \ln \nu_{iht}, \tag{4}$$

where

$$\theta_i = \frac{\sigma_i}{\sigma} \qquad \text{and} \qquad \nu_{iht} = \left(\frac{\tilde{\nu}_{iht}(1-\beta^{\tau_i})}{1-\beta}\right)^{\sigma\theta_i}.$$

Expression (4) shows that, conditional on buying good i, a household will choose a higher-quality version the richer is the household (the higher is c_{ht}), the lower is the quality-adjusted price of the good (the lower is z_{it}), and the greater is the household taste for the good (the higher is ν_{iht}).

From (4), the elasticity of demand for quality with respect to c is θ_i for good 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). The quality slope is important not only for how quality responds to nondurable consumption, but also for how quality responds to shifts in the quality-adjusted price of good i. Suppose the cost of producing good i increases 1 percent, raising z_i by 1 percent. If there is no response in the level of quality bought, the unit price of i rises by 1 percent. But, this increase in z_i will induce the quality of good i purchased to fall by $\sigma\theta_i$ percent.

B. *Predicting Growth in Quality*

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

$$\overline{\Delta x_i} = \overline{\Delta q_i} + \overline{\Delta z_i}, \tag{5}$$

where Δx_i denotes the growth rate (i.e., log first difference) of x. Expression (5) derives from averaging log first differences of (2) across buying households. The overbars denote time averages, which we use to emphasize that the empirical implementation will involve time-averages of inflation rates (specifically, over 1980–1996). As shown in (5), the only variation remaining is across goods i.

In contrast to unit price inflation rates, BLS inflation rates aim to measure price changes *holding quality constant.* We denote the BLS inflation rate for good i as $\overline{\Delta p_i}$. If the BLS measure is unaffected by changes in quality, then it equals $\overline{\Delta z_i}$. If, instead, the BLS is able to net out only a fraction $(1 - \mu)$ of quality growth, then $\overline{\Delta p_i}$ is given by

$$\overline{\Delta p_i} = \overline{\Delta z_i} + \mu\overline{\Delta q_i}. \tag{6}$$

If the BLS deflator perfectly measures price per unit of quality, then μ is zero. If the BLS understates quality improvements and overstates

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 IV.)

inflation, then μ is positive. As stressed by Jack E. Triplett (1997), however, the BLS might overstate quality improvements and understate inflation, in which case μ is negative.

Combining (5) and (6) yields the following relation between BLS and unit price inflation:

$$(7) \qquad \overline{\Delta p_i} = \mu \overline{\Delta x_i} + (1 - \mu)\overline{\Delta z_i}.$$

Our strategy is to estimate μ—the fraction of quality growth that goes unmeasured—by regressing BLS inflation on unit price inflation, as in (7), treating $(1 - \mu)\overline{\Delta z_i}$ as an error term. Now, as (5) shows, unit price inflation is clearly correlated with true inflation $\overline{\Delta z_i}$. 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 (their θ_i values) to construct these instruments.

Taking first differences of (4) and averaging across households and time, the growth rate of quality demanded for good i is given by

$$(8) \qquad \overline{\Delta q_i} = \theta_i \overline{\Delta c} - \sigma \theta_i \overline{\Delta z_i} + \overline{\Delta \nu_i}.$$

This says that goods with steeper quality slopes (higher values of θ_i) should exhibit faster growth in quality in response to economywide income and consumption growth ($\overline{\Delta c} > 0$). Quality should also rise faster for goods with declining relative prices ($\overline{\Delta z_i} < 0$), particularly if the good has a steep quality slope.

Substituting (8) into (5), unit price inflation equals

$$(9) \qquad \overline{\Delta x_i} = \theta_i \overline{\Delta c} + (1 - \sigma\theta_i)\overline{\Delta z_i} + \overline{\Delta \nu_i}.$$

The first term in (9) says that goods with steeper quality slopes display faster average growth in unit prices in response to economywide consumption growth, reflecting their faster growth in quality. This means that differences across goods in the quality slopes θ_i should be a relevant instrument for differences in unit price inflation rates $\overline{\Delta x_i}$ across goods. 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 turn out to be excellent predictors of which goods display faster unit price inflation. The correlation between a good's quality slope and its average rate of unit price inflation is 0.51.

The relevance of the quality slope as an instrument for $\overline{\Delta x_i}$ does not guarantee its validity, that is, its orthogonality to the error term $(1 - \mu)\overline{\Delta z_i}$ in (7). Our identifying assumption is that differences in the estimated quality slopes across goods (θ_i values) are uncorrelated with quality-adjusted relative price shifts across goods ($\overline{\Delta z_i}$ values):

$$(10) \qquad \text{Cov}(\theta_i, \overline{\Delta z_i}) = 0 \quad \text{across } i.$$

If (10) holds, then θ_i is a valid instrument for $\overline{\Delta x_i}$ in (7).[5] We provide evidence in Section IV to support this identifying assumption. For example, we show that factor prices did not rise faster, nor did total factor productivity (TFP) grow slower, in the industries producing goods with steeper quality slopes.

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). For each good, the unit price, quality-adjusted price, and BLS price are normalized to equal each other in the base period ($x_0 = z_0 = p_0$). Growth from period 0 to period 1 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. For this reason, the increase in x_i from x_0 to x_1 is much larger for cars than that for vacuums. If the BLS price reflects only quality-adjusted prices, then the growth in p_i, from p_0 to p_1,

[5] More formally, the condition is

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

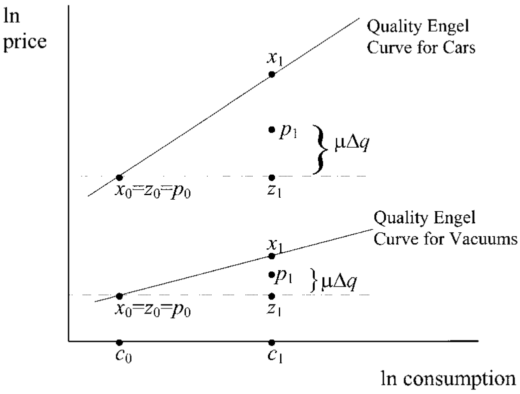

FIGURE 1. CLIMBING UP QUALITY ENGEL CURVES (HOLDING QUALITY-ADJUSTED PRICES CONSTANT)

Notes: x = unit price = qz; z = quality-adjusted price; p = BLS price = $q^{\mu}z$.

should not be greater for cars than that for vacuums. Figure 1 depicts no changes in quality-adjusted prices ($\Delta z_i = 0$) for both cars and vacuums, so the BLS prices should not change at all. But to the extent that μ is greater than zero, faster quality growth in x_i for cars than for vacuums will be mirrored in faster growth in p_i. As drawn, about 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 ⅔.

Of course, quality-adjusted prices do change over time, and at different rates for different goods. We do not rule out such shifts in our IV estimation of μ. We assume only that the shifts are orthogonal to the quality slopes identified off of cross sections of households, as expressed by condition (10). Moreover, we actually utilize changes in quality-adjusted prices to construct another instrument for quality growth. To see this, first rewrite (9), ignoring constant terms, as

$$(11)\qquad \overline{\Delta x_i} = \theta_i(\overline{\Delta c} - \sigma\overline{\Delta z}) - \sigma(\theta_i - \theta)(\overline{\Delta z_i} - \overline{\Delta z}) + (1 - \sigma\theta)\overline{\Delta z_i} + \overline{\Delta \nu_i},$$

where $\theta = (1/N)\sum_{i=1}^{N}\theta_i$ is the average value of θ_i across goods and $\overline{\Delta z} = (1/N)\sum_{i=1}^{N}\overline{\Delta z_i}$ is the average true inflation rate across goods. This expression suggests the interaction term $(\theta_i - \theta)\overline{\Delta z_i}$ 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 $(\theta_i - \theta)\overline{\Delta z_i}$ as an instrument requires an assumption that parallels (10), but with the quality slopes uncorrelated with $(\overline{\Delta z_i})^2$ rather than with $\overline{\Delta z_i}$.

Construction of the instrument $(\theta_i - \theta)\overline{\Delta z_i}$ is complicated by the fact that $\overline{\Delta z_i}$ is not directly observable. We observe the BLS inflation rates, but these are equal to the true inflation rates only if $\mu = 0$. Rearranging (7), true inflation can be related to BLS inflation and unit price inflation by

$$(12)\qquad \overline{\Delta z_i} = \frac{1}{1-\mu}(\overline{\Delta p_i} - \mu\overline{\Delta x_i}).$$

This construction requires a value for μ, the parameter of interest. Therefore, its use in forming another instrument entails nonlinear estimation of μ. We return to these issues in Section IV.

Given an estimate for μ, we can estimate quality growth and unmeasured quality growth for our set of consumer durables. If the BLS succeeds in fully netting out the impact of quality change, then quality growth is simply the growth rate in unit prices for good i minus its BLS rate of price increase. When $\mu > 0$, however, quality growth for good i equals

$$(13)\qquad \overline{\Delta q_i} = \frac{\overline{\Delta x_i} - \overline{\Delta p_i}}{1-\mu}.$$

The extent of *unmeasured* quality growth for good i is similarly given by

$$(14)\qquad \overline{\Delta q_i} - (\overline{\Delta x_i} - \overline{\Delta p_i}) = \frac{\mu(\overline{\Delta x_i} - \overline{\Delta p_i})}{1-\mu}.$$

We highlight two limitations of our approach here. First, we are making the strong assumption that μ—the extent of quality growth that seeps into BLS inflation rates—is the same

TABLE 1—PERCENT BUYING INDIVIDUAL CONSUMER GOODS IN A TYPICAL YEAR

Good	(1) Number buying	(2) Percent buying	(3) Percent buying 2+ (of those buying)
Carpeting	4,835	7.4	19.6
Curtains and drapes	9,251	14.2	20.1
Mattress and springs	5,911	9.1	10.5
Bedroom furniture	6,649	10.2	17.2
Sofas	5,347	8.2	8.4
Living room furniture	8,731	13.4	30.5
Kitchen/dining room furniture	5,131	7.9	12.5
Baby furniture and equipment	4,915	7.5	35.8
Outdoor furniture	5,731	8.8	14.2
Refrigerators and freezers	4,365	6.7	12.9
Clothes washers	3,205	4.9	10.3
Clothes dryers	2,235	3.4	11.4
Stoves and ovens	2,563	3.9	15.1
Microwave ovens	3,567	5.5	5.2
Window air conditioners	1,435	2.2	5.1
Televisions	10,346	15.9	11.0
Radios	8,224	12.6	15.2
Stereos	4,953	7.6	12.7
Rugs	5,757	8.8	15.6
Window coverings	5,256	8.1	14.2
Clocks	5,218	8.0	11.3
Lamps and lights	8,695	13.3	18.9
Telephones[a]	9,379	14.4	18.6
Lawn and garden equipment	8,112	12.4	20.0
Power tools	6,247	9.6	25.6
Vacuums	5,045	7.7	8.7
Sewing machines	1,202	1.8	4.4
Small kitchen appliances	20,270	31.1	33.6
Heaters	6,530	10.0	12.0
Hard flooring	1,088	1.7	33.8
Office furniture	2,311	3.5	13.8
Hand tools	10,298	15.8	34.5
Men's suits	8,663	13.3	23.1
Men's coats and sportscoats	18,837	28.9	35.9
Men's and boys' sleepwear	9,592	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	9,124	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's 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
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	6,614	10.1	19.4
Cars	13,483	20.7	13.5
Trucks	4,489	6.9	7.2
Tires	25,597	39.3	34.7
Eyeglasses and contacts	18,901	29.0	32.6
Sports and exercise equipment	16,989	26.1	47.3
Bicycles	5,401	8.3	19.5

TABLE 1—*Continued.*

Good	(1) Number buying	(2) Percent buying	(3) Percent buying 2+ (of those buying)
Camping equipment	3,237	5.0	28.9
Fishing and hunting equipment	6,903	10.6	45.4
Winter/water sports equipment	6,523	10.0	34.5
Playground equipment	1,263	1.9	10.5
Musical instruments	4,814	7.4	36.5
Photographic equipment	6,665	10.2	17.3
Personal care appliances	10,389	15.9	25.3
Calculators[b]	4,625	7.1	11.3
Typewriters[a]	1,610	2.5	5.6
Mean	11,321	17.4	26.6
Median	6,784	10.4	20.1
Standard deviation	9,911	15.2	17.1
Maximum	41,274	63.3	76.6
Minimum	1,088	1.7	4.4

Notes: Sample: Cross sections of households in the 1980–1996 U.S. Consumer Expenditure Surveys. Observations: 65,189 household-years. Fraction buying: percentage of households buying 1 or more of the good in a 12-month span. Fraction buying 2+ (of those buying): percentage of buying households who buy more than 1 in a 12-month span.

[a] 1983–1996. The 1980, 1981, and 1982 Consumer Expenditure Surveys did not include this item.

[b] 1982–1996. The 1980 and 1981 Consumer Expenditure Surveys did not include this item.

across goods. Our cross-good estimation methodology does not afford good-by-good estimates of quality growth or quality bias.[6] Second, the overbars indicate time-averages, meaning we do not produce period-by-period estimates of quality growth and quality bias. We avoid higher-frequency estimates for a couple of reasons. As we describe in the following section, the number of annual unit price observations per good in the CEX renders the annual growth rates sufficiently noisy that we see it as preferable to time-average the growth rates over the entire 1980–1996 sample. We are also concerned that a demand shift toward goods with steep quality slopes may lead to a short-run relative increase in factor prices for those products. If so, at cyclical and higher frequencies, this would go against the identifying assumption that differences in the quality slopes are uncorrelated with quality-adjusted relative price shifts.

II. Comparing Data on Unit Price Inflation and BLS Price Inflation

A. *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 BLS.[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

[6] We can allow for limited differences in the value of μ across goods. For instance, in Section V we explore the possibility that measurement is more accurate (i.e., μ is closer to zero) for goods with greater expenditure shares or goods for which the BLS sometimes employs direct quality adjustments.

[7] The BLS conducts two separate surveys of consumer expenditures, an interview survey and a diary survey. Our data are based on the interview surveys. We obtained the 1980–1994 data from the University of California, Berkeley (2000) and the 1995–1996 data from the U.S. Bureau of Labor Statistics (1998, 1999).

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

The first column of Table 1 reports, for the pooled 1980 to 1996 cross sections, the number of households purchasing each good. These numbers provide the sample sizes for estimating the quality slopes in Section III. The second column presents the fraction of the sample buying. This ranges from a low of 1.7 percent for sewing machines to a high of 63.3 percent 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.

B. *Unit Price Inflation*

We measure increases in unit prices for the 66 goods as follows. Expenditures are grouped by year of purchase. We 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).[10] 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.[11]

The resulting inflation rates appear in the first column of Table 2. Weighting by importance in the CPI, average unit prices rose by 0.97 percent per year (relative to the CPI for nondurables) on average across the 66 durable goods. The most extreme declines were for microwave ovens (−9.2 percent) and heaters (−4.1 percent). The most extreme increases were for trucks (3.7 percent), sports and exercise equipment (2.8 percent), and jewelry (2.8 percent).

C. *BLS Inflation*

BLS prices are not the same as CEX unit prices for a number of reasons. One important

[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 does not compromise the validity of our instruments, however, unless any such bias from lumping purchases happens to be more important for goods that experience faster true inflation.

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. Of much more relevance to our work, however, the extent of this discrepancy is typically only very weakly related to household nondurable consumption (and hence will have little effect on the quality slopes we estimate below). 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.

[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 that in Table 1. For instance, living room furniture is separated into tables versus chairs; men's and boys' sleepwear, as well as sweaters, are separated for men's versus boys'; winter sporting goods are separated from water sporting goods. We aggregated goods in these 12 cases to be consistent with BLS categories. We aggregate on the basis of expenditure shares in the CEX. Similarly, in Section IV 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] We obtained all BLS price deflators from the BLS web site (U.S. Bureau of Labor Statistics, 2000).

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

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.[12] If people switch toward more expensive models within a CEX category, then the average unit price for the category should rise, although 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 that 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 Karin E. Moses (1997) describe BLS "item substitution" procedures in detail. They report that about 30 percent of BLS items disappear at least once every year (p. 323). Moreover, in the three years that 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 percent of price quotes in 1983, 1984, and 1995, respectively, but accounted for 20, 34, and 31 percent of the nonapparel inflation rate in those years (see their Tables 5 and 6 pp. 338–40). 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 in 1997 for the 66 goods we study.[13] The substitution rate varies from 2.4 percent per month for calculators and typewriters to 38.3 percent for women's and girls' dresses, and averages 13.8 percent 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 percent in 1997.

Conditional on the need for an item substitution, the BLS follows one of three procedures. In roughly one-half of substitutions (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 percentage of substitutions judged comparable for our goods. It is the most common procedure, occurring 46 percent of the time for our goods (weighted by their CPI share). For certain categories 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 22 percent of the time for our goods. It is most common for trucks, cars, and men's suits. For the rest of the substitutions 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. Column (5) of Table 3 reports that this procedure was used in 32 percent of item substitutions for our goods. Thus, for the majority (78 percent) of the

[12] 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 Brent R. 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, because 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 updates the establishments at which it collects prices only 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 Boskin Commission (Boskin et al., 1996) estimate such "outlet bias" to be about 0.1 percent per year.

[13] We obtained this item-substitution data from Appendix VIII in U.S. General Accounting Office (1999).

TABLE 2—CHANGES IN UNIT VERSUS BLS PRICES

Good	(1) 1980–1996 Annual percent change in unit prices	(2) Subperiod annual percent change in unit prices	(3) Subperiod annual percent 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's 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
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

TABLE 2—*Continued.*

Good	(1) 1980–1996 Annual percent change in unit prices	(2) Subperiod annual percent change in unit prices	(3) Subperiod annual percent change in BLS prices	(4) Column (2)–column (3) (= implied BLS quality change)
Sports and 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	−0.39	−1.33	0.94
Median	−0.36	−0.41	−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

Notes: 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:

1980–1981: Stoves and ovens; microwave ovens.

1980–1982: Window air conditioners; small kitchen appliances; heaters; hand tools; womens' skirts and pants; womens' sleepwear; girls' coats and jackets.

1980–1983: Rugs; clocks; mens' and boys' sweaters; womens' sweaters and vests; trucks.

1980–1984: Luggage; sports and exercise equipment; playground equipment.

1980–1985: Telephones; hunting and fishing equipment; calculators; typewriters.

1980–1986: Watches; jewelry; eyeglasses and contacts.

1990–1996: Sewing machines. 1992–1996: Camping equipment. 1993–1996: Microwave ovens.

item substitutions for our goods, 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 fully) netted out of the BLS inflation rate for those goods.

An example may be useful to illustrate these ideas. Suppose a particular Toyota Camry is included among the items in the CPI, as is a more expensive Lexus. Suppose further that these car models remain unchanged from one year to the next, but that households become richer so that unit sales of the Lexus rise relative to those of the Camry. No item substitutions need occur. The BLS, by putting a fixed weight on each model across the years, will register no inflation at all from the quality upgrading. In this example there would be quality growth, but none of it would go unmeasured. (This is a "passive" quality adjustment that rightly occurs as a result of the fixed BLS weights.) Now suppose that, because of rising demand for quality, the makers improve the quality of each model in a new year. Item substitutions should then be triggered. For cars the BLS sometimes makes "active" or direct quality adjustments, but this is not typical for all goods or even for our set of durable goods. Whether direct adjustments are made or not, however, the possibility arises that item substitutions are associated with quality upgrading that is not entirely netted out in BLS inflation calculations.

Buying improved models that hit the market, as in this car example, may be an important way in which quality growth occurs over time. Our quality slopes, although estimated off of cross-

TABLE 3—BLS ITEM SUBSTITUTIONS AND METHODS OF QUALITY ADJUSTMENT, 1997

Good	(1) Percent weight in December 1997 CPI	(2) 1997 item-substitution rate (in percent)	(3) Percent of substitutions "comparable"	(4) Percent of substitutions "direct"	(5) Percent of substitutions "linked"
Carpeting	0.021	11.8	0	11	89
Curtains and drapes	0.052	6.5	57	0	43
Mattress and springs	0.158	6.9	49	0	51
Other bedroom furniture	0.203	6.3	36	0	64
Sofas	0.225	7.7	50	0	50
Living room tables	0.179	4.5	33	0	67
Kitchen/dining room furniture	0.146	7.0	32	0	68
Baby furniture and equipment	0.044	8.0	62	0	38
Outdoor furniture	0.025	19.4	62	0	38
Refrigerators and freezers	0.084	9.6	91	0	9
Clothes washers	0.057	8.5	100	0	0
Clothes dryers	0.035	5.4	94	0	6
Stoves and ovens	0.038	9.5	89	0	11
Microwave ovens	0.043	12.2	93	0	8
Window air conditioners	0.015	5.3	75	0	25
Televisions	0.128	14.1	62	0	37
Radios	0.023	14.7	42	0	58
Stereos	0.075	15.4	41	0	59
Rugs	0.062	7.0	58	3	39
Window coverings	0.060	2.5	77	0	23
Clocks	0.011	11.3	44	0	56
Lamps and lights	0.049	10.5	62	0	38
Telephones	0.012	4.8	33	0	67
Lawn and garden equipment	0.085	9.8	86	1	13
Power tools	0.035	3.2	64	0	36
Vacuums, sewing machines[a]	0.042	10.6	76	2	22
Small kitchen appliances, heaters[a]	0.072	8.0	56	0	44
Hard flooring	0.007	2.9	25	0	75
Office furniture	0.122	7.4	31	0	69
Hand tools	0.026	3.7	56	0	44
Men's suits	0.193	4.7	51	39	9
Men's coats and sportscoats	0.119	12.0	67	11	22
Men's and boys' sleepwear	0.044	5.9	94	0	6
Men's and boys' sweaters	0.043	20.2	54	16	30
Men's pants	0.212	5.4	79	11	10
Boys' coats, suits, and sportscoats	0.035	22.0	76	0	24
Women's and girls' coats	0.192	26.3	56	18	27
Women's and girls' dresses	0.284	38.3	56	21	23
Women's sweaters and vests	0.072	27.7	61	20	19
Women's skirts and pants	0.394	14.4	63	21	16
Women's and girls' sportswear	0.086	29.1	75	7	19
Women's sleepwear	0.068	24.9	82	0	18
Women's suits	0.168	32.4	57	23	20
Men's footwear	0.224	7.9	82	4	14
Boys' and girls' footwear	0.154	15.1	83	0	17
Women's footwear	0.341	11.4	79	3	18
Watches	0.078	8.7	77	0	23
Jewelry	0.323	7.5	66	3	31
Luggage	0.035	10.9	60	0	40
Cars	4.811	16.5	30	35	35
Trucks	1.120	15.6	23	50	26
Tires	0.256	2.5	83	0	17
Eyeglasses and contacts	0.335	2.9	50	13	37
Sports and exercise equipment	0.210	8.1	47	2	51
Bicycles	0.181	10.3	78	0	22

TABLE 3—*Continued.*

Good	(1) Percent weight in December 1997 CPI	(2) 1997 item-substitution rate (in percent)	(3) Percent of substitutions "comparable"	(4) Percent of substitutions "direct"	(5) Percent of substitutions "linked"
Camping/fishing/hunting equipment[a]	0.046	7.5	55	2	43
Winter/water sports equipment	0.163	8.3	45	2	53
Playground equipment	0.001	37.5	0	0	100
Musical instruments	0.062	5.3	56	4	41
Photographic equipment	0.048	7.0	74	0	26
Personal care appliances	0.011	8.9	71	0	29
Calculators, typewriters[a]	0.004	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
Nonresidential price quotes		3.3	58	13	29
Nonresidential, nonvehicle		3.0	63	8	29

Notes: Item-substitution rate: percentage of price quotes for which a substitute replaced the previous month's item. (Because 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.

[a] Four pairs of categories had to be combined because of lack of finer BLS data.

sectional choices among *existing* goods, could very well predict the rate at which consumers shift into improved models, not just switch among incumbent models. First, retailers may be upgrading the quality of all models they sell (and manufacturers all models they produce) in response to rising demand for quality. Demand for quality should be rising faster where the quality slopes are steeper—the first term in equation (8). New models may appear all along the price–quality menu, not just at the very top. Second, if all qualities become cheaper, then our quality slopes interacted with the change in quality-adjusted prices should predict where quality upgrading will be rapid. This is the second term in (8).

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 earlier, 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 three-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 are 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

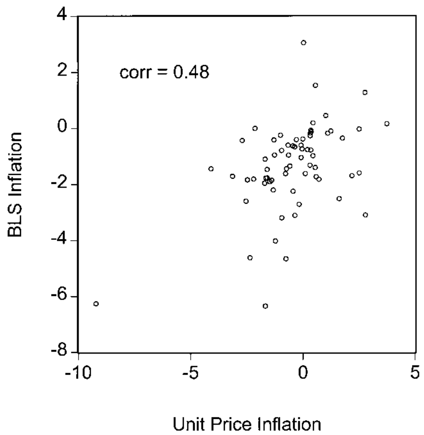

FIGURE 2. INFLATION RATES FOR EACH OF THE 66 GOODS

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)]. Weighting by CPI shares, the mean difference across the 66 goods is 1.46 percent faster inflation in unit prices than in BLS prices. An interpretation of this is that the BLS incorporates quality growth of 1.46 percent per year on average for these goods.[14] Note that these quality adjustments are partly "active" (involving item substitution procedures), but may be mostly "passive" (inflation in unit prices from consumers upgrading among existing goods does not contaminate BLS fixed-weight inflation). Moulton and Moses (1997) report that "active" quality adjustments amounted to between 0.28 and 0.44 percent in 1995. If this is typical of active adjustments over 1980–1996 for our set of durables, then most of our 1.46 percent estimate would stem from passive BLS quality adjustments.

III. 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. 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.

Generalizing (4) from the consumer's problem to include measurement error and ignoring terms that do not vary across households, we have

$$(15) \quad \ln \hat{x}_{iht} = \theta_i \ln \hat{c}_{ht} + \ln \nu_{iht} + \varepsilon_{iht},$$

where

$$\varepsilon_{iht} = \ln\left(\frac{\hat{x}_{iht}}{x_{iht}}\right) - \theta_i \ln\left(\frac{\hat{c}_{ht}}{c_{ht}}\right)$$

and $\hat{x}_{iht}$ and $\hat{c}_{ht}$ denote a household's reported values for x_{iht} and c_{ht}.[15] The distinction between the reported and true values for x_{iht} and c_{ht} contributes the error term ε_{iht}. In arriving at (15) we are assuming that households face the same quality-adjusted prices z_{it}. In pooling cross sections of households from different years of the CEX, we add dummies for year, region, and city (versus rural) to control for likely differences in prices across time and space. In addition to heterogeneity in c_{ht}, 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 ν_{iht} in (15).[16] For five of

[14] 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.

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

[16] Additional variation in this preference parameter is another potential source of error in (15). Selection of household h into the sample of purchasers of good i based on the household's value of ν_{ih} 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. It is not clear how this selection will bias the *relative* estimates of θ_i across goods, which is central to our constructed instrumen-

the goods (carpeting, curtains and drapes, window coverings, lamps and lights, and hardwood flooring), we are concerned that richer households 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 $\hat{c}_{ht}$ in (15) to be a household's total nondurable consumption. Our measure of nondurables is narrower than that in the National Income and Product Accounts, in that we exclude clothing and footwear from nondurables. To the extent that there is measurement error in a household's response for c_{ht}, as allowed for in (15), an ordinary least squares (OLS) estimate of θ_i will be biased toward zero. For this reason we instrument for $\hat{c}_{ht}$ 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 $\hat{c}_{ht}$ 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 1-percent increase in nondurable spending is associated with about a 1-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 zero at the 0.05 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 loglinear 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.[17] Figures 3 and 4 illustrate by comparing the linear and nonparametric Engel curves for cars and vacuums, respectively. Cars are a high-expenditure good among those with the steepest quality slopes. Vacuums are a high-expenditure good among those with the flattest quality slopes. The linear estimates track the nonparametric estimates quite well, especially over the (-0.5, $+0.5$) range containing 88 percent of the log consumption observations.

In estimating the quality slopes we have assumed that the higher unit prices paid by richer households reflect the purchase of higher-quality versions of goods, not higher price markups *conditional* on quality. Might richer households pay higher markups than poorer households do for the same quality of good? For cars, at least, this does not appear to be the case. Pinelopi Koujianou 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. We touch on this issue again below, but note that markups would have to covary a lot with nondurable consumption to explain Table 4. If Household A has twice the nondurable consumption of Household B, then Household A typically pays about 76 percent more for a consumer durable. This is substantially larger than most estimates of the *level* of markups.

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 constructed as follows. For each good a household's quantity of

tal 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, be biased down by the entry into the markets of consumers with a relatively low preference for the good.

[17] 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 percent of the ln c observations.

TABLE 4—ENGEL CURVE SLOPES

Good	(1) Quality	(2) Quantity	(3) Quality/ (quality + quantity) (in percent)
Carpeting	0.75 (0.08)	0.61 (0.05)	55
Curtains and drapes	0.93 (0.04)	0.39 (0.03)	70
Mattress and springs	0.62 (0.04)	0.65 (0.04)	49
Bedroom furniture	0.70 (0.05)	0.75 (0.04)	48
Sofas	0.76 (0.04)	0.53 (0.04)	59
Living room furniture	0.75 (0.04)	0.63 (0.03)	54
Kitchen/dining room furniture	0.84 (0.06)	0.67 (0.04)	56
Baby furniture and equipment	0.46 (0.04)	0.45 (0.05)	50
Outdoor furniture	0.93 (0.05)	1.00 (0.04)	48
Refrigerators and freezers	0.46 (0.04)	0.35 (0.04)	57
Clothes washers	0.28 (0.04)	0.37 (0.05)	43
Clothes dryers	0.32 (0.05)	0.67 (0.06)	32
Stoves and ovens	0.41 (0.06)	0.48 (0.06)	46
Microwave ovens	0.16 (0.03)	0.53 (0.05)	23
Window air conditioners	0.26 (0.08)	0.31 (0.07)	46
Televisions	0.41 (0.03)	0.50 (0.03)	45
Radios	0.37 (0.03)	0.65 (0.03)	37
Stereos	0.34 (0.04)	1.05 (0.04)	25
Rugs	1.07 (0.05)	0.85 (0.04)	56
Window coverings	1.11 (0.06)	0.56 (0.04)	66
Clocks	0.74 (0.04)	0.50 (0.04)	60
Lamps and lights	0.81 (0.04)	0.80 (0.03)	50
Telephones	0.59 (0.03)	0.73 (0.03)	45
Lawn and garden equipment	0.25 (0.05)	0.57 (0.03)	30
Power tools	0.29 (0.04)	0.60 (0.04)	32
Vacuums	0.24 (0.04)	0.75 (0.04)	25
Sewing machines	0.19 (0.10)	0.36 (0.08)	35
Small kitchen appliances	0.39 (0.02)	0.65 (0.02)	38
Heaters	0.41 (0.03)	0.28 (0.04)	60
Hard flooring	0.64 (0.15)	0.30 (0.11)	68
Office furniture	0.71 (0.07)	1.11 (0.06)	39
Hand tools	0.55 (0.03)	0.58 (0.03)	49
Men's suits	0.68 (0.02)	1.52 (0.03)	31
Men's coats and sportscoats	0.61 (0.02)	1.24 (0.02)	33
Men's and boys' sleepwear	0.37 (0.02)	0.97 (0.03)	27
Men's and boys' sweaters	0.46 (0.01)	1.13 (0.02)	29
Men's pants	0.45 (0.01)	0.71 (0.01)	39
Boys' coats, suits, and sportscoats	0.48 (0.02)	0.68 (0.03)	41
Women's and girls' coats	0.57 (0.01)	1.08 (0.02)	34
Women's and girls' dresses	0.67 (0.01)	0.96 (0.01)	41
Women's sweaters and vests	0.50 (0.01)	1.11 (0.02)	31
Women's skirts and pants	0.52 (0.01)	0.89 (0.01)	37
Women's and girls' sportswear	0.47 (0.01)	1.28 (0.02)	27
Women's sleepwear	0.44 (0.01)	0.97 (0.02)	31
Women's suits	0.72 (0.02)	1.44 (0.03)	33
Men's footwear	0.52 (0.01)	0.57 (0.01)	48
Boys' and girls' footwear	0.50 (0.01)	0.43 (0.02)	54
Women's footwear	0.62 (0.01)	0.70 (0.01)	47
Watches	0.68 (0.02)	0.70 (0.02)	49
Jewelry	1.13 (0.02)	1.06 (0.02)	52
Luggage	0.90 (0.04)	1.54 (0.04)	37
Cars	0.94 (0.03)	0.39 (0.02)	71
Trucks	0.93 (0.06)	0.33 (0.04)	74
Tires	0.42 (0.02)	0.67 (0.02)	38
Eyeglasses and contacts	0.27 (0.02)	0.75 (0.02)	26
Sports and exercise equipment	0.59 (0.03)	1.30 (0.03)	31

TABLE 4—*Continued.*

Good	(1) Quality	(2) Quantity	(3) Quality/ (quality + quantity) (in percent)
Bicycles	0.43 (0.05)	0.67 (0.04)	39
Camping equipment	0.50 (0.06)	0.95 (0.06)	34
Fishing and hunting equipment	0.66 (0.04)	0.59 (0.04)	53
Winter/water sports equipment	0.81 (0.05)	1.45 (0.04)	36
Playground equipment	0.68 (0.13)	0.71 (0.08)	49
Musical instruments	0.37 (0.07)	0.90 (0.05)	29
Photographic equipment	0.65 (0.04)	0.97 (0.04)	40
Personal care appliances	0.34 (0.02)	0.90 (0.03)	28
Calculators	0.35 (0.04)	0.81 (0.04)	30
Typewriters	0.57 (0.09)	0.68 (0.07)	46
Mean	0.57	0.76	43
Median	0.54	0.69	41
Standard deviation	0.23	0.31	13
Maximum	1.13	1.54	74
Minimum	0.16	0.28	23
Weighted mean	0.76	0.62	56

Notes: Sample: Cross sections of households in the 1980–1996 U.S. Consumer Expenditure Surveys. (1982–1996 for calculators, and 1983–1996 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.

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:

$$(16) \quad \hat{\Omega}_{iht}/\bar{\Omega}_i = (\text{quantity Engel curve slope}) * \ln \hat{c}_{ht} + \text{error term}.$$

As with the quality Engel curves, in estimating the quantity Engel curves we instrument for nondurable consumption in quarters 3 and 4 with nondurable 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, in (16) we divide a household's purchase quantity of good i by the mean purchase quantity for good i in the sample.[18]

The estimates in Table 4 show that the quantity Engel curves differ sharply across goods. All goods display elasticities of at least 0.28, and 14 goods display 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 for by the quality Engel curve ranges from a low of 23 percent for microwaves to a high of 74 percent for trucks. On average the quality response to nondurable consumption is actually

[18] The percentage response in a household's expenditure is expressed relative to average household expenditure on good i, rather than the household's own expenditure on the good, which in many cases is zero.

We are not interpreting the estimates of the quantity Engel curve slopes in terms of structural parameters. We present these estimates as one benchmark for judging the magnitudes of the estimated quality slopes. Structural interpretation of the quantity Engel slopes is complicated, for one, by the fact that we observe only expenditures rather than stocks for the goods. This is discussed in detail in Bils and Klenow (1998), Section III.

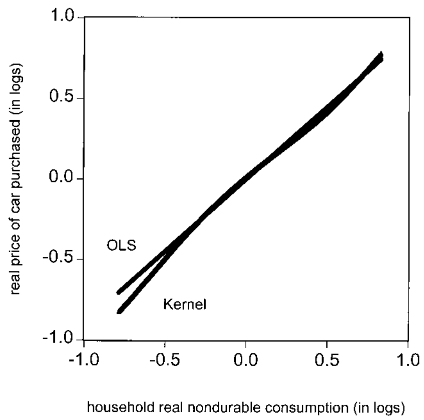

FIGURE 3. QUALITY ENGEL CURVE FOR CARS

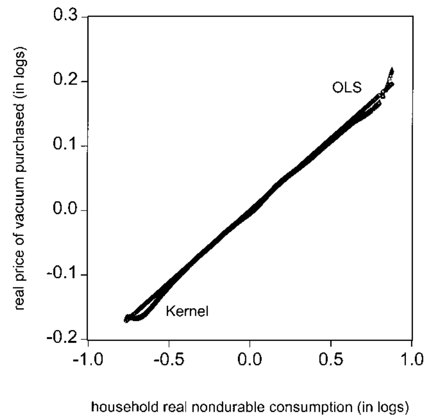

FIGURE 4. QUALITY ENGEL CURVE FOR VACUUMS

more important in magnitude than the quantity response: when weighted by expenditures, the average share accounted for by the quality Engel curve is 56 percent.

Although we take Table 4 as supportive of an important role for quality upgrading in growth, we caution readers (especially potential calibrators) against a literal interpretation. The quality slopes could be systematically biased upward or downward. For instance, they might be biased upward if richer households tend to pay higher markups, controlling for quality, or if richer households lump more purchases together in the CEX. Nonseparabilities of durables and nondurables consumption could bias the slopes in either direction, as could selection bias. The slopes could be biased downward if measurement error in nondurable consumption remains even after instrumenting with lags. Moreover, part of the quality Engel curve could be misattributed to the quantity Engel curve if richer households replace their durables with greater frequency. By replacing more frequently richer households may have better, less-depreciated durables on average. This would not be captured in the unit price they pay, and therefore would not show up in our quality slopes.[19]

Fortunately, our IV estimation of μ (the share of quality growth that goes unmeasured) is robust to many forms of bias in the quality slopes. A fixed additive bias in the slopes (say from a constant elasticity of the durables markup with respect to nondurable consumption) would have no effect on $\hat{\mu}$, or even on the first-stage coefficient from regressing unit price growth on the quality slopes. Proportional bias in the slopes would bias the first-stage coefficient, but would have no effect on the second-stage estimation of μ. Finally, differential bias in the quality slopes that was uncorrelated with true inflation would reduce the first-stage fit and hence the precision of the second-stage estimation, but would not bias $\hat{\mu}$.

IV. Estimating Quality Changes

A. *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 slope 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 slopes for the sample of 66 goods. Microwave ovens are an outlier because

[19] For a number of our goods this could be investigated systematically using the durable goods inventory portion of the CEX.

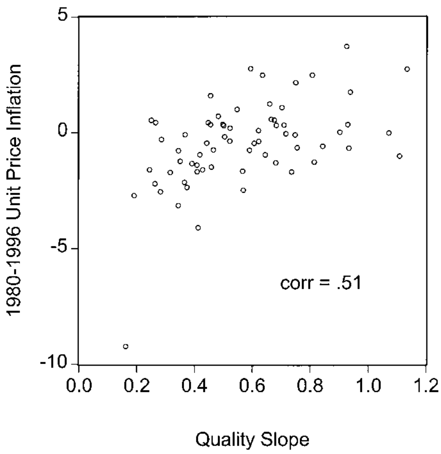

FIGURE 5. QUALITY SLOPES AND UNIT PRICE INFLATION RATES FOR 66 GOODS

of their 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 (9) predicts a faster unit price inflation rate the steeper the 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. The coefficient implies that a unit increase in the quality slope (roughly the difference between the steepest and flattest slopes among the 66 goods) is associated with 4.24 percent faster unit price inflation over 1980–1996.

To check robustness of this first-stage regression we reestimated 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 percent per year. Row 2 of Table 5 shows that, excluding these two goods, the coefficient on θ_i falls slightly from 4.24 to 4.13 percent and the t-statistic rises considerably to 12.1. We also reestimated after eliminating jewelry, rugs, and window coverings from the sample. These goods exhibit 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.

Because cars and trucks are outliers in terms of their CPI weight in the regressions, together receiving 48-percent weight (39 percent for cars; 9 percent for trucks), in row 4 of Table 5 we report results omitting them. The results change only modestly (coefficient 3.21 percent versus 4.24 percent in the full sample, t-statistic 5.2 versus 5.8), so 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 4.11 percent with a t-statistic of 4.7. Finally, one could argue that the apparel categories (16 of the 66 categories, with 21 percent of the CPI weight in the regressions) are not independent observations, so row 5 uses only the 50 nonapparel categories. Although the coefficient is modestly lower than the baseline estimate (3.66 percent versus 4.24 percent) and the t-statistic is lower, reflecting the smaller sample and coefficient (3.4 versus 5.8), the coefficient remains highly significant.

Could the coefficient from this regression (e.g., the 4.24-percent baseline estimate) plausibly reflect consumers upgrading quality faster for goods with steeper quality slopes? From (9), we anticipate a coefficient on the quality slope equal to $\overline{\Delta c} - \sigma\overline{\Delta z}$.[20] Growth in real per capita nondurables consumption $\overline{\Delta c}$ averaged 1.26 percent per year from 1981 to 1995. Relative to the price of nondurables, BLS prices for our set of durable goods fell by 0.82 percent per year on average (weighting goods by their CPI shares). For illustration suppose that σ equals 1 (utility is logarithmic in nondurable consumption). Then $\overline{\Delta c} - \sigma\overline{\Delta z}$, the impact of the quality slope on inflation in unit prices, should be 2.08 percent [=1.26 percent − (−0.82 percent)].

The preceding calculation assumes, however, that there is no unmeasured quality growth for

[20] This assumes that θ_i is uncorrelated with both $\overline{\Delta z_i}$ and $\overline{\Delta \nu_i}$. Orthogonality of θ_i and $\overline{\Delta z_i}$ is required for validity of θ_i as an instrument, but orthogonality of θ_i and $\overline{\Delta \nu_i}$ is not.

TABLE 5—PREDICTING CHANGES IN UNIT PRICES

Weighted least-squares regressions	Coefficient on θ_i (percent)	Adjusted R^2	Number of observations
Full sample of goods	4.24 (0.72) $t = 5.8$	0.93	66
Minus 2 + SD Δx_i extremes (excludes microwave ovens and trucks)	4.13 (0.34) $t = 12.1$	0.98	64
Minus 2 + SD θ_i extremes (excludes jewelry, rugs, and window coverings)	4.25 (0.75) $t = 5.7$	0.93	63
Minus CPI weight extremes (excludes cars and trucks)	3.21 (0.62) $t = 5.2$	0.31	64
Minus apparel (excludes the 16 clothes and shoes categories)	3.66 (1.06) $t = 3.4$	0.93	50

Notes: The weighted least squares weights are equal to December 1997 CPI shares. The dependent variable is Δx_i (percent unit price growth for good i) averaged over 1980–1996. The regressor is θ_i, the quality slope for good i. According to equation (9) in the text, the coefficient on θ_i should equal $\Delta c - \sigma\Delta z$. This regression is the first-stage regression for the instrumental variables estimation that follows in Table 6.

durables.[21] Filling the gap between 2.08 percent and the 4.24-percent coefficient in Table 5 requires unmeasured quality growth of 2.16 percent per year on average across our durable goods (if $\sigma = 1$). This is in line with the degree of unmeasured quality growth we estimate for our goods below (2.2 to 2.4 percent per year).

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. For the coefficient of 4.24 percent, the average implied quality growth is 3.2 percent per year. This is reasonably close to what we estimate below (3.7 to 3.8 percent).

Table 5 is the first-stage regression for the second-stage estimation of μ (see Table 6 below). It is important to emphasize that the first-stage prediction of time-series unit price inflation with cross-sectional quality slopes need not have worked. As (9) shows, our strategy requires enough change in the level of nondurable consumption or in the relative price of our durables. If 1980–1996 had been a period over which $\overline{\Delta c} - \sigma\overline{\Delta z}$ was stagnant, the quality slopes would have had no predictive power. But as the adjusted R^2 values in Table 5 demonstrate, the first-stage fit is ample, consistent with evidence that nondurable consumption grew and durables prices fell.

We assume that a good with a steep quality slope exhibits fast unit price inflation because of fast quality growth, not fast true inflation. A good with a steep quality slope 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), because a steep quantity Engel curve also predicts rising demand for the product over time. Repeating the first row regres-

[21] The discussion also assumes no unmeasured quality growth for nondurables. However, each percent of unmeasured quality growth in nondurables understates both $\overline{\Delta c}$ and $\overline{\Delta z}$ by 1 percent. Thus, for $\sigma = 1$, it has precisely offsetting effects on the two terms in $(\overline{\Delta c} - \sigma\overline{\Delta z})$.

sion, now including the good's quantity Engel curve, yields an insignificant coefficient on the quantity Engel curve of −0.89 percent (standard error 0.66), and one with the opposite sign predicted by upward-sloping marginal cost. The coefficient on the quality Engel curve falls, but remains highly significant at 3.50 percent with a standard error of 0.91 and *t*-statistic of 3.9.

Related, 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 the coefficient on the quality Engel curve from its baseline value of 4.24 percent to 4.78 percent (standard error 0.37, *t*-statistic 13.0).

Finally, we investigated whether aspects of the producing industries suggest goods with steeper quality slopes might have increasing quality-adjusted prices, which would violate identifying condition (10). True inflation might be faster for labor-intensive industries (those with low capital–labor ratios or high labor shares in value added) or industries with rapid growth in wages or materials prices and slow growth in TFP. Using four-digit manufacturing industries in the NBER Productivity Database, we examined how these industry characteristics correlated with the quality slope of the good produced. We averaged over 1980–1996 and weighted each industry by its CPI share. We found mostly small and insignificant correlations of these industry variables with the quality slopes across the 66 goods. The only exceptions were with the equipment capital-to-labor ratio (correlation + 0.20 and *p*-value 0.11) and with TFP growth (+0.43, *p*-value 0.0003). These correlations suggest, if anything, that true inflation might be *lower* for goods with steeper quality slopes. The significantly more rapid TFP growth is particularly suggestive, because we might have expected a negative correlation given our finding (below) that inflation is more overstated for goods with steeper quality slopes.[22]

We conclude that a good's quality slope robustly predicts its unit price inflation rate.

B. *Quality Engel Curves and BLS Price Inflation*

We are now prepared to estimate μ, the share of quality growth that gets mismeasured as inflation. Our estimate of μ is identified by combining (7), (9), and (13) with conditions that the residual $\overline{\Delta z_i}$ be orthogonal to our instruments θ_i and $(\theta_i - \theta)\overline{\Delta z_i}$. Estimation is by Generalized Method of Moments (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 61.8 percent as much as do unit prices in response to quality upgrading predicted by a good's quality slope. If the BLS quality adjustments, which average 1.46 percent per year across our goods, miss 61.8 percent of quality growth, then true quality growth equals 3.82 percent per year [=1.46 percent/(1 − 0.618)]. The quality bias in BLS inflation rates for our goods would then be 2.4 percent per year (3.82 percent minus the BLS quality adjustments of 1.46 percent).

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

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

[22] It is also difficult to explain the differences in rates of unit price inflation predicted in Table 5 on the basis of changing price markups over marginal cost. For instance, the difference in quality slopes between cars and vacuums of 0.7 predicts unit prices for cars would increase by 3 percent per year relative to unit prices for vacuums, accumulating to 60-percent greater inflation for cars over the period of 1980 to 1996. Markups would need to have increased markedly for goods with steep quality slopes, relative to other goods, to play an important part in such large relative changes in unit prices.

TABLE 6—ESTIMATES OF μ, QUALITY GROWTH, AND INFLATION BIAS

Instrument set ↓	μ	Average quality growth (percent per year)	Upward inflation bias (percent per year)	Adjusted R^2
θ_i	0.618 (0.125) $t = 4.9$	3.8	2.4	0.56
θ_i, $(\theta_i - \theta)\Delta z_i$	0.601 (0.119) $t = 5.0$	3.7	2.2	0.57

Notes: The number 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: The estimating equation is $\Delta p_i = \mu \cdot \Delta x_i + (1 - \mu) \cdot \Delta z_i$. This is equation (7) 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 percent 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 $1.46/(1 - \mu)$. This is equation (13) in the text. Upward inflation bias: The BLS misses the fraction μ of total quality growth, which equals $1.46 \cdot \mu/(1 - \mu)$. This is equation (14) in the text.

have slower rates of cost-reducing technological progress or face faster growth in factor prices, then their prices will be rising for a reason in addition to quality upgrading. We presented evidence in the preceding subsection that this is not the case. As one additional effort to address this possibility, we reestimated excluding goods with rates of BLS price inflation more than two standard deviations away from the mean of −1.33 percent per year. This eliminated five goods from the sample (microwaves, TVs, radios, telephones, and luggage) and lowered the estimate of μ to 0.477 (standard error 0.104, t-statistic 4.6). This would imply an inflation bias of 1.3 percent per year, versus the 2.2 percent implied by estimation of μ with the full sample of goods.[23]

How do our estimates of bias compare to other estimates in the literature? The Boskin Commission (Boskin et al., 1996) estimated quality bias of 0.6 percent per year for the overall CPI, but 1.0 percent per year for the consumer durable subcomponent (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 percent per year from 1947 to 1983, and at least 1.0 percent 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

[23] We conducted a number of other robustness checks:

(i) Weighting goods equally lifted the estimate of μ to 0.812 (standard error 0.199, t-statistic 4.1).

(ii) Excluding cars and trucks (the CPI weight extremes) resulted in a μ estimate of 0.884 (0.222, 4.0).

(iii) Excluding the 16 clothing and shoes categories lowered the estimate of μ to 0.561 (0.145, 3.9).

(iv) Excluding the unit price growth extremes (microwaves, trucks) boosted the estimate of μ to 0.680 (0.153, 4.5).

(v) Excluding quality slope extremes (jewelry, rugs, window coverings) lowered the estimate to 0.568 (0.117, 4.9).

We recalculated $\overline{\Delta x_i}$ based on the periods BLS prices are available, rather than using the entire 1980 to 1996 period. Using this alternative measure of $\overline{\Delta x_i}$ to construct the instrument $(\theta_i - \theta)\overline{\Delta z_i}$ had very little effect. The estimate of μ became 0.622 (0.122, 5.1). Using this alternative measure in the first-stage regression (9), as well as in constructing the instrument $(\theta_i - \theta)\overline{\Delta z_i}$, led to a μ estimate of 0.657 (0.163, 4.0).

Finally, we also tested whether the μ coefficient systematically differs in size for those goods for which the BLS implicitly makes a large quality adjustment (goods with a large value in the final column of Table 2) or goods that constitute larger shares in consumer spending. We found no significant interactions.

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).

To summarize, differences in quality slopes successfully predict differences in unit price inflation rates. These differences pass through into differential rates of BLS price inflation. Our preferred estimate of μ is about 0.60, which implies about 2.2-percent 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 0.363 and 0.849. 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 ($\mu = 0.363$, our point estimate minus two standard errors), and that this generated a bias of at least 0.8 percent per year. This would be associated with quality growth of 2.3 percent per year, only 1.5 percent per year of which was netted out by BLS adjustments.

V. Conclusion

We estimated quality Engel curves for 66 consumer durables from pooled cross sections of households in the 1980 through 1996 U.S. Consumer Expenditure Surveys. We used their slopes to predict the speed of quality upgrading for the 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 percent per year for our goods. We estimated that BLS quality adjustments captured about 40 percent of this upgrading, with roughly 60 percent, or 2.2 percent 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 flowed through into measured inflation, biasing consumer durables inflation by at least 0.8 percent per year over 1980–1996.

We should add that our approach does not yield good-by-good or period-by-period estimates of quality growth and quality bias. The approach provides an overall diagnostic on the extent of quality bias in official inflation rates for a set of goods. Yet a strength of our approach relative to using hedonics is that our approach does not require detailed information on the attributes of goods. Our approach requires data only on unit prices and on simple attributes of *buyers.* In this paper we have focused on the richness of buyers, but other attributes that are correlated with unit prices could be used as well, such as age or household composition (number of kids, number of workers, etc.). With scanner data from supermarkets, department stores, and the like, data on unit prices could become accessible for a much wider set of goods than our 66 durable goods comprising 12 percent of the CPI. One must be able, however, to match these unit prices to buyer attributes.[24]

[24] Unit prices for some nondurables might be available in the Diary Surveys of the CEX, which would contain the necessary buyer attributes.

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