Price Deflators for High Technology Goods and the New Buyer Problem

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A B S T R A C T

Some items in a household's market basket, notably durable goods, are purchased only occasionally. In contrast, standard price measures implicitly assume that consumers purchase some amount of every available good in every period. The occasional purchase of an existing good by a new buyer generates a "new buyer" problem that is similar to the traditional "new goods" problem generated by the entry of new goods.

This paper uses an idea introduced by Fisher and Griliches (1995) and Griliches and Cockburn (1995) to develop price indexes for goods that are not purchased in each period. A comparison of the resulting price indexes with those calculated under the standard assumption suggests that the sharp declines typically exhibited by price indexes for many high technology goods may be overstated. However, it is impossible to make any definitive statements about the numerical magnitude of this potential problem. These preliminary findings simply underscore the importance of further research to study this problem for high tech goods and to explore the possibility that similar problems may arise for other durable goods.

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1. **Introduction**

Some items in a household's market basket are purchased only occasionally. Durable goods—like new vehicles, computers and household appliances—are typically purchased only every few years. Nondurable goods may also be purchased infrequently when the purchase involves indivisibilities—toothpaste, laundry detergent—adjustment costs—goods purchased at far-away outlets—or other types of market imperfections.[1] Finally, many services are also purchased only on occasion—legal advice, visits to physicians, vacations, visits to movies or restaurants.

In contrast, standard price measures implicitly assume that consumers purchase some amount of every available good in every period. For example, traditional index number theory assumes that a representative consumer purchases some amount of *all* the existing goods in *every* period.[2] Similarly, the model typically used to justify hedonic analysis (Rosen (1974)) allows heterogeneous consumers to purchase different *quantities* of goods each period, but nonetheless assumes that consumers purchase at least *some* amount of *all* available goods every period.

The effect that entry and exit of *goods* has on standard price measures–the traditional "new goods" problem—has been studied extensively.[3] In contrast, the effect of entry and exit of *buyers* has received relatively little attention. In both cases, the market prices used in standard measures no longer necessarily reflect consumers' internal valuations of goods. For the new goods problem, one solution is to use Hicksian reservation prices to measure price change experienced by consumers. This approach was applied by Fisher and Griliches (1995) and Griliches and Cockburn (1995) (hereafter, FGC) for what one might call the "new buyer" problem in prescription pharmaceuticals.

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[1] Index number theory typically relies on static optimization problems to describe the consumer problem while these cases inherently point to a dynamic model for the consumer. For durable goods, the seminal article is Hall and Jorgenson(1967). For nondurable goods, see, for example, Betancourt and Gauchi (1992), Feenstra and Shapiro (2000), and Hendel and Nevo(2003).

[2] A notable exception is Feenstra(1995) who constructs price indexes that allow the entry and exit of consumers making discrete choices over products. His approach, however, is to consider specific functional forms and other cases where the utility functions for individual consumers can be aggregated up to an aggregate utility function that serves the same role as that of a representative consumer.

[3] See "New Goods and New Outlets," Chapter V of the National Academy's report titled "At What Price?"

Building on their work, this paper considers price indexes for goods that are purchased intermittently and constructs FGC-type indexes for several high-technology goods, a class of goods with important macroeconomic implications.

A preliminary look at this problem for these goods suggests that numerical differences in the FGC and standard indexes can be quite large. Moreover, in most of the cases considered here, the FGC price indexes show slower price declines than standard indexes, suggesting that standard indexes may overstate the rate of price declines for some high tech goods. However, theoretically, the bias can work in either direction and, as shown below, calculations done using the Prud'homme and Yu(2003) data on prepackaged software provide one example where the bias goes the other way.

Hobijn(2001), Harper(2003) and Feenstra and Knittel (2004) have explored other potential sources of bias that might lead constant-quality price measures constructed using standard methods to overstate the observed price declines for high technology goods. More generally, Bils and Klenow (2001a, 2001b) empirically assessed the ability of standard methods to adequately capture quality change for a wide array of consumer durable goods. As such, this paper contributes to a strand of the literature that is concerned with the ability of standard measures to provide accurate measures of technological change and product innovation.[4]

The paper is organized as follows. After a brief look at the reservation-price solution to the new-goods problem, the FCG approach is reviewed and extended slightly to define an FGC-type Fisher index. The key requirement in applying their approach is that one be able to place bounds on consumers' reservation prices. Section 3 provides a formal definition of "reservation prices" in the context of a simple discrete-dynamic choice model and uses that framework to explore conditions under which reservation prices are well defined for durable goods like IT products. The fourth section shows that, under fairly weak assumptions, the downward-sloping price contours typically seen for high technology goods may be used to bound reservation prices and construct FGC-type

[4] Some recent studies in this literature have explored the sensitivity of price indexes for high technology goods to the particular choice of measurement technique (Aizcorbe, Corrado and Doms(2000)), the assumption of perfect competition (Aizcorbe(2002) and Hobijn (2002)); others have used growth accounting frameworks to assess how much of the movements in standard indexes may be directly attributed to technological change (Aizcorbe, Oliner and Sichel(2003) and Flamm(2003).

indexes. A comparison of the FGC price measures to standard ones suggests the differences in the two indexes may be nontrivial. Given the potentially important implications for economic growth and productivity, these preliminary findings call for further work to pin down the potential importance of this issue.

2. The New Goods Problem and the Role of Reservation Prices

The importance of entry and exit for price measurement has been studied in the context of the "new goods" and the "new outlets" problems.[5] The reservation price solution to that problem forms the basis for what follows and is reviewed here.

Consider a Fisher index that measures aggregate price change from time t-1 to t that is stated as the ratio of two weighted averages of price relatives:

$$F^{STD}_{t,t-1} = \frac{\Sigma_i \, \omega_{i,t-1} \, (P_{i,t} \, / \, P_{i,t-1})}{\Sigma_i \, \omega_{i,t} \, (P_{i,t-1} \, / \, P_{i,t})} \tag{1}$$

where the $\omega_{i,t-1}$'s are nominal expenditure weights and the $(P_{i,t}/P_{i,t-1})$ are price relatives.

The "new goods" problem is that if a new good is introduced at time t, a price for that good does not exist for the previous period (t-1) and the price relatives necessary to form price measures like the Fisher index cannot be formed.[6]

Chart 1 illustrates this "new goods" problem and the "reservation price" solution in the context of the downward-sloping price contours that characterize prices for many high technology goods and perhaps other goods as well.[7] Assume that the models in chart 1 are defined such that quality is constant over the life of the good so that quality

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[5] See, for example, Fisher and Shell (1972) and Reinsdorf(1993).

[6] This is different from the "new goods" problem faced by statistical agencies. There, goods that are being tracked by the agency are obsoleted by a new good and the disappearance of the old good and appearance of the new good must be dealt with. See Pakes (2003) for a full discussion of this problem. Here, the FGC approach provides a "fix' for a particular type of matched-model indexes. Unlike procedures used by statistical agencies, these matched-model indexes are typically constructed using near-universe data and exploit such data to split out quality change from pure price change—see, for example, Grimm (1998), Aizcorbe, Corrado and Doms (2000), Silver and Heravi (2001), and Abel, Berndt and White (2003))

[7] The shape of these profiles for DRAM memory chips are discussed in Flamm(1989) and Irwin and Klenow(1994) and for microprocessor chips in Aizcorbe (2002).

change occurs only when new goods appear or old goods exit. Here, model 2 replaces model 1 at time t and the "new goods" problem is that $P_{2,t-1}$ does not exist.

The goal of price indexes is to separate out changes in prices that result from changes in quality from those that result from other influences (i.e., "pure price change"). The reservation price solution measures "pure price change" explicitly and quality change implicitly. Thus, given an estimate for the consumer's reservation price at t-1 (i.e., $P^R_{2,t-1}$) one can measure "pure price change" as the ratio of the price paid for the new good at time t to the reservation price for the good at t-1 (i.e., $P_{2,t}/P^R_{2,t-1}$). To see how this explicit measurement of "pure price change" implicitly measures quality change, note that had the consumer purchased the old model at t-1, then the difference between the price he paid (for the old good) and his reservation price (for the new good) at time t-1 would be a measure of his valuation of the quality improvement in the new good at t-1.[8]

In practice, estimates for reservation prices are either estimated econometrically using hedonic techniques—as in the imputation method—or by making the assumption that the implicit price change for the representative consumer is the same as the actual price change measured using observed prices—as in matched-model methods. In terms of chart 1, the hedonic imputation implicitly attributes some part of the gap between the two market prices at time t to quality change and the rest to pure price change while the matched-model method assumes that the entire vertical distance is the "market's valuation" of the quality improvement in the new good.

Finally, note that, despite the literature's emphasis on the entry of new goods, exiting goods also create a problem. In measuring prices from time t to t+1, one would, in principle, need a reservation price for the exiting model.

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[8]It can be shown that, in general, the use of a reservation price to fix the new goods problem implies a valuation of the quality improvement for the new good that is some function of the gap between the prices in both periods. Define quality change as the difference between changes in average prices and changes in a constant-quality price index. In the simple example in chart 1, the change in average prices from t-1 to t+1 is $P_{2,t+1}/P_{1,t-1}$. Using a simple geometric mean of price change as our index, a chained price index that uses a reservation price for the new good would be the product of the (multiplicative) price changes from t to t+1: $(P_{2,t+1}/ P_{2,t})$ and the average price changes from t-1 to t (i.e, $(P_{1,t}/ P_{1,t-1})^{½} (P_{2,t}/ P^R_{2,t-1})^{½}$, where $P^R_{2,t-1}$ is the reservation price: $I^{GEO}_{t-1,t+1} = (P_{2,t+1}/ P_{2,t})(P_{1,t}/ P_{1,t-1})(P_{2,t}/ P^R_{2,t-1})$. The difference between this index and the average price change gives a geometric average of quality differences in the two goods at time t-1 and time t, where the quality differences are measured as the gaps between the two price contours: $(P_{2,t+1}/P_{1,t-1}) / [(P_{2,t+1}/ P_{2,t})(P_{1,t}/ P_{1,t-1})(P_{2,t}/ P^R_{2,t-1})] = (P^R_{2,t-1}/P_{1,t-1})^{½} (P_{2,t}/P_{1,t})^{½}$

3. Indexes for Intermittent Purchases

When consumers do not purchase every good in every period, price indexes must take into account the presence of new and exiting buyers. The FGC papers provide a framework based on the reservation price approach that may be used to define a Paasche index that includes new buyers. As is usually the case, the Paasche index is not affected by the presence of exiting buyers because it uses the current period as its point of reference: that is, the index values price change using current period expenditures and those purchases are zero for buyers that exited the market at t-1. To account for exiting buyers, a straightforward extension of the FGC idea is applied here to the Laspeyres index and that resulting index is then combined with the FGC Paasche to form a Fisher Index.

3.1 The FGC Paasche Index

FGC expanded our understanding of the new goods problem by considering the case where a new good is introduced but heterogeneous consumers do not necesarily purchase the new good at the period of introduction. In their particular application, the patent for a branded drug expires and a generic drug enters the market. But, the slow diffusion of knowledge about the generic drug generates staggered switching to the new good: not everyone switches to the lower-cost generic drug in the period of introduction even if the two drugs are chemically identical because it takes time for consumers to realize that the generic is a safe alternative to the higher-priced branded drug.

In this context, FGC make three important contributions that have wider applicability than the particular case of prescription goods.[9] First, they define a Paasche index that explicitly accounts for the fact that some buyers are new buyers:

$$(2)\qquad \Pi^{NC}_{t,t-1} = [\Sigma_i \Sigma_b P_{i,t} X_{i,t}{}^{b})] \;/\; \Sigma_i [(\Sigma_{b\in C} P_{i,t-1} X_{i,t}{}^{b}) + (\Sigma_{b\in N} P^{R,b}{}_{i,t-1}\, X_{i,t}{}^{b})]$$

where "NC" denotes that the Paasche index measures price change for new and

[9] This paper ignores another important contribution of the FGC work. They also provide a COLI interpretation to their Paasche Index. However, because there are well-known problems with applying the COLI interpretation to durable goods (or, more broadly, to goods where the decision to make a purchase is dynamic in nature), the interpretation is not exploited here.

continuing buyers, summations are over goods, i, and buyers, b; and $b \in C$ and $b \in N$ denote continuing and new buyers, respectively. As with any Paasche index, the numerator measures actual expenditures in the current period. The denominator evaluates the current period market basket for continuing buyers using the market prices they paid for the good ($P_{i,t-1}$) and the market basket for new buyers using their (individual) reservation prices ($P^{R,b}_{i,t-1}$). Note that although market prices do not vary over buyers, reservation prices are buyer-specific.

FGC then propose a way to deal with the unobserved reservation prices. In (2), consumer heterogeneity complicates things because, in principle, one needs a reservation price for *each* consumer. However, FGC show that all one needs is an average reservation price. In particular, one can adapt (2) to allow for new buyers by simply replacing individual reservation prices in the base period with an average reservation price ($\underset{\sim}{\mathbf{P}}^{R}_{i,t-1}$):

$$(3) \qquad \Pi^{NC}_{t,t-1} = [\Sigma_i \Sigma_b P_{i,t} X_{i,t}{}^{b}] \;/\; [\, \Sigma_i (\Sigma_{b \in C} P_{i,t-1} X_{i,t}{}^{b}) + (\underset{\sim}{\mathbf{P}}^{R}{}_{i,t-1}\; \Sigma_{b \in N} X_{i,t}{}^{b})\,]$$

where $\underset{\sim}{\mathbf{P}}^{R}{}_{i,t-1} = [\Sigma_{b \in N} P^{R,b}{}_{i,t-1} X_{i,t}{}^{b}] \;/\; [\Sigma_{b \in N} X_{i,t}{}^{b}]$.

Finally, to measure this average reservation price, FGC show that if one can place bounds on consumers' reservation prices, and if one assumes that the reservation prices are uniformly distributed within those bounds, then FGC show that one can calculate the average reservation price as the average of the bounds. Although the uniform distribution is, in some sense, unsatisfying, as pointed out by FGC, there does not seem to be any obvious reason for choosing any distribution in particular.[10]

3.2 Extension

[10] In terms of chart 1, measuring price change over the life of the first chip—from t-6 to t—involves measuring price change over six time periods, and if new buyers exist in each of those time periods, then one would need to make an assumption about the distribution of reservation prices at each of those six points in time. Although there are probably weaker distributional assumptions under which the average of the bounds will give one the average of the distribution—if the bounds are symmetric about the mean, for example—that would generate clumps of consumers with reservation prices exactly between market prices at each period over the life of the good and there's no reason to believe that reservation prices will fit this pattern.

One can, in principle, apply the FGC idea to the case of exiting buyers—those buyers that purchased the good in the base period but not the current period. In particular, the following Laspeyres index measures price change for exiting and continuing buyers:[11]

(4) $$\Lambda^{XC}_{t,t-1} = [\, \mathbf{P}_{i,t} (\Sigma_{b\in C} X_{i,t-1}{}^{b}) + \Sigma_i \mathbf{P}^{R}{}_{i,t} (\Sigma_{b\in X} X_{i,t-1}{}^{b}) \,] \;/\; [\, \Sigma_i P_{i,t-1} (\Sigma_b X_{i,t-1}{}^{b})]$$

Here, the denominator is unchanged—it measures actual expenditures in the base period—but the numerator now values the base period market basket using market prices for continuing buyers and reservation prices for exiting buyers.

This Laspeyres index may then be combined with the Paasche index in (3) to form a Fisher Ideal index that allows for the presence of new and exiting buyers:

(5) $$F^{FGC}{}_{t,t-1} = [\, \Lambda^{XC}{}_{t,t-1} \; \Pi^{NC}{}_{t,t-1} \,]^{1/2}$$

As shown in the Appendix, sufficient conditions for the numerical equivalence of the FGC and standard Fisher indexes are that (1) the gap between the average reservation price and the market price be the same for new and exiting buyers—i.e., $(\mathbf{P}_{i,t-1} / \mathbf{P}^{R}{}_{i,t-1}) = (\mathbf{P}^{R}{}_{i,t} / \mathbf{P}_{i,t})$—and (2) that markets be stable in the sense that the number of entering buyers just equals that of exiting buyers. These conditions suggest that price growth will be understated in growing markets—where entry exceeds exit—and overstated in shrinking markets—where the reverse is true.

3.3 Applicability to Durable Goods

The remainder of the paper focuses on this problem as it relates to durable goods purchases. In this context, two issues with potential implications for price measurement must be considered: what is the relevant price and when are these prices well-defined.

For non-durables that are not storable, the purchase and consumption of the good occur in the same period, so that the observed price may be used to measure changes in consumer welfare as well as the value of the industry's output. In contrast, durable goods

[11] Just as the Paasche index is the relevant index for the price change experienced by new buyers—the Paasche uses the current period quantities to compare prices—the Laspeyres is the relevant index for exiting buyers—it uses base period weights to compare prices.

are purchased in one period but the stream of services is consumed over time so that the price at the time of acquisition cannot be used to measure consumer welfare. For the latter, the relevant ”good” is the per-period flow of services and the attendant price is the per-period cost—either a user cost or a rental price.[12] This is the preferred measure for constructing cost-of-living indexes (COLIs) where one is interested in the *use* of the durable.[13] Hence, an index based on acquisition prices does not have a clear COLI interpretation except under the (strong) assumption that changes in acquisition prices track those of user costs.[14,15]

But, what if the focus is the construction of price deflators to value industry output? What is the relevant price for valuing production (rather than the use) of the good? For production taking place *today*, it makes sense to value the good at today's acquisition price because the acquisition price gives the price that consumers are willing to pay for the durable good and, thus, their valuation of the good at the time of purchase. In what follows, acquisition prices are used to split out quality differences from pure price change in the construction of a deflator to measure the value of real output.[16]

The second issue that arises in the application of the FGC method to the case of durable goods has to do with reservation prices. Consumer purchases of durable goods—particularly the large-ticket items like computers—are likely to be one-time purchases. The implication of one-time purchases for the FGC indexes is that there are no continuing buyers—all buyers are either new or exiting buyers.

The Paasche index then measures price change for new buyers only and the Laspeyres measures price change for exiting buyers. But, notice that this assumes that

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[12] See, for example, Hall and Jorgenson (1967).

[13] Feenstra and Knittel (2004) approach this issue from a COLI perspective, in part, because they are interested in constructing an input price rather than a price deflator. Moreover, their data allow them to base their estimates of any potential bias on user cost estimates rather than acquisition prices.

[14] Note that if all durable goods were actually leased or rented, the problem disappears. In that case, the “good” is defined as the flow of services each period and the “price” is the rental price. In effect, the problem has been redefined to fit the static problem that forms the basis for standard price measures.

[15] The unfortunate fact is that, in practice, the paucity of data with which to construct user costs or rental prices has led many to construct simple indexes based on acquisition prices. In fact, the majority of available indexes for durable goods—including some that we examine below—are based on acquisition prices.

[16] This ignores the case where production is also dynamic—for example, the building of Boeing jets requires many months of production—it's not at all clear when output should be recorded and which prices should be used to value it.

reservation prices exist for buyers that have already made a purchase. As argued below, it's not clear that exiting buyers have a well-defined reservation price in the period after making a purchase.[17]

In what follows, it is assumed that consumers making a purchase at time t leave the market once they make a purchase and that therefore, do not have a well-defined reservation price at time t+1. Moreover, the focus is narrowed to the case of one-time purchases—a plausible assumption for many durables.

The implication for measurement when all consumers are one-time buyers is that only the Paasche is well defined. It is the only index that focuses on buyers that were in the market in both periods and that measures their assessment of changes in quality over the period. Given reservation prices for new buyers, the FGC Paasche index provides a best guess at pure price change:[18]

$$(3') \qquad \Pi^{NC}_{t,t-1} = [\Sigma_i \Sigma_b P_{i,t} X_{i,t}{}^b] \; / \; [\, \Sigma \, (\underset{\sim}{\mathbf{P}}^R{}_{i,t-1} \, \Sigma_{b \in N} X_{i,t}{}^b) \,]$$

4. FGC Indexes for High Tech Goods

This section applies the FGC idea to the case of high technology goods. The notion of a "reservation price" is pinned down in order to explore when a reservation price exists and how reservation prices are likely to change over time.

4.1 Reservation Prices for Durable Goods

In general, one can think of a consumer's "reservation price" as the maximum price he is willing to pay for a good. Discrete, dynamic choice models provide a framework that allows one to explore the properties of these reservation prices under fairly general conditions. Suppose there are J_t goods on the market at time t=1,…T and

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[17] This problem arises in the traditional new goods problem in that the use of reservation prices requires, in principle, that the good exist in the period prior to introduction (See the discussion in Fisher and Griliches (1995). Similarly, in the present paper, the construction of a Laspeyres index requires that the consumer "exist" or be in the market after making a purchase.

[18] The traditional interpretation of a Paasche index is as a lower bound to a true cost of living index (COLI). As discussed earlier, however, the COLI interpretation is not relevant for durable-goods price indexes that are based on acquisition prices.

that each of the I households already owns an (older) version of the durable that was bought at time $\tau < t$. Households face $J_t + 1$ choices each period; they either buy one of the J_t durables on the market or they keep the durable they already own.

The I households in the market face per-period utility functions of the form $U(z,s(q_{jt},), p_{jt}(q_{jt}))$, where z is a vector of the household's characteristics, and both the service flow s( ) and user cost p( ) depend on the characteristics of the good (q_{jt}) a vector that includes the age of the durable they already own. An intuitive way to think about the service price is to define it as the erosion of the value of the asset that occurs over the period. Let λ_t be the fraction of the value at acquisition that remains at time t, where the fraction is, in turn, a function of the good's characteristics, including age. Then, the erosion of the asset from t-1 to t is defined as the rental cost:

$$p(q_{j\tau}) = \lambda_{t-1}(q_{j\tau}) / \lambda_t(q_{j\tau}) P_{j\tau}$$

This rental cost for the asset held by the household is a function of the age of the asset—an attribute included in the vector of characteristics—and the acquisition price. Although the rental cost is a function of the acquisition price, in this specification, the relevant price change for the consumer's COLI is not: $p_t / p_{t-1} = \lambda_t / \lambda_{t-1}$.

Following the notation in Keane and Wolpin (1994), define $d_j(t)=1$ if the household chooses option j at time t, and $d_j(t)=0$ otherwise. And assume that the decisions are mutually exclusive so that $\Sigma_{j=0,J+1} d_j(t)=1$. Then, the per-period utility function may be written as:

$$\Sigma_{j=0,J+1} \; d_j(t) \; U_{jt.} \tag{6}$$

Conditional on the household's characteristics and all the options available at time t—including the durable they already own—(S(t))—each household chooses a path so as to maximize future utility. Given Markov assumptions, there are J+1 Bellman equations that give the time t expected utility associated with each option:

(7) $$V_{jt}= U(z,s(q_{jt},), p_{jt}(q_{jt})) + \delta E[V(S(t), d_j(t)] .$$

The first term is the utility for option j at time t and the second term is the expected future utility conditional on having chosen option j at time t (that is, of all the future decisions that might be made, the second term gives the *expected* utility across all possible paths). The optimal choice, V_{*t}, is the option that gives the highest expected utility, $V^*_t > V_{jt}$, for all $j \neq *$.

Given this framework, one may define a reservation price for each good on the market as the highest (acquisition) price for the good such that the consumer would choose that good over all other options, conditional on actual price of the other options: the reservation price for option j is the highest price for option j that satisfies $V_{jt}(P^R_{jt}) > V_{kt}$ for all k, and depends on all current and future service flows and rental prices for all goods. Thus, although utility depends on service flows and user costs, the reservation price is defined as a hypothetical acquisition price. One may define such a reservation price for each option.

In what follows, it is assumed that consumers leave the market in the period following a purchase and that, therefore, a reservation price does not exist in that period. A consumer will choose to be "in the market" when it is likely that he can find an option that could sufficiently raise his utility over his current option (V_{ot}). Immediately after making a purchase, the good becomes a "second-hand" good and its value typically falls sharply. In the framework above, this is represented as a high service price in the first period of acquisition (high $\lambda_{\tau+1}(q_{j\tau}) / \lambda_\tau(q_{j\tau})$) that makes it relatively expensive to hold a durable in the first period and inexpensive to hold it in subsequent periods. If that service price is sufficiently high, the consumer will not find an (unanticipated) alternative in the next period that will bring him sufficiently high utility to offset the costs involved in switching and will, therefore, exit the market. A framework that allows for search costs would only make exit more likely.

It is also assumed that reservation prices fall over time. As pointed out above, reservation prices depend on the prices and quality levels of all current and future goods so that changes in the prices of substitutes and complements will affect reservation prices. For example, a decline in the price of a substitute lowers the reservation price for a good. Moreover, in markets for high-technology goods—and perhaps other markets with rapid rates of product innovation—substitution exists along an intertemporal dimension as well as contemporaneously. So, the reservation price for a good available today depends not only on the prices and qualities of currently-available goods, but also on those of goods that are expected to enter the market in the future. In this intertemporal dimension, an important determinant of the reservation prices for today's goods is the amount of time the consumer must wait before the good appears. In particular, as the arrival of future, higher-quality goods approaches, the reservation prices for goods available today will fall. This is exactly the explanation often given for rapid declines in market prices over the life of high tech goods. If this intertemporal substitution effect dominates that of contemporaneous substitutes and complements in generating movements of reservation prices, then reservation prices will fall over time. As seen below, this turns out to be an assumption that is important for bounding reservation prices.

4.2 Bounding Reservation Prices when Price Contours are Downward-Sloping

The challenge in constructing the FGC-type indexes is in finding a way to measuring reservation prices. In what follows, the patterns of price change typically exhibited by high technology goods are exploited to obtain bounds for reservation prices that may ultimately be used to form a price index for one-time buyers.[19]

High tech goods like semiconductors, personal computers, and other consumer electronics typically have price contours that are downward sloping. The shape of these contours can be generated by cost- or demand-side factors (See Flamm(1987) and Irwin and Klenow(1994)) for a discussion of the role of learning-by-doing in generating these price contours for memory chips and Aizcorbe and Kortum(2004) for a vintage-capital model that generates these contours without appealing to learning economies).

In either case, these downward-sloping price contours reflect what consumers are willing to pay for the good and may be used to obtain bounds for their reservation prices. Chart 2 traces out a typical price contour, where a new good enters the market at time t-3.

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[19] This framework will not accommodate cases where the durable good held by the household "dies" and is replaced by another good in the same period. In that case, a reservation price does not exist at t-1 and the FGC indexes cannot be calculated.

Consider a Paasche measure of price change over t,t-1 (i.e., $\Pi_{t,t-1}$). For one-time buyers, the index contains only new buyers whose reservation prices are such that they do not purchase the new good until time t. The reservation-price approach to measure the price change experienced by a buyer is the ratio of the price he actually paid at time *t* to his reservation price at time t-1 (i.e., $P_{i,t}/P^R_{i,t-1}$).

To see how downward sloping contours allow one to bound his reservation price at time t-1, note that, for the current period, the fact that the buyer *did* purchase the new good implies that his reservation price was *at least as high* as the market price in that period (time t). Similarly, for the earlier period, the fact that the buyer *did not* purchase the new good implies that his reservation price was *at least as low* as the market price in that period. As long as his reservation price did not rise over the period—the assumption discussed in the previous section—then the observed prices in the two periods provide bounds for his reservation price. That is,

$$(8) \qquad P_{i,t} < P^R_{i,t} \leq P^R_{i,t-1} < P_{i,t-1} \, ,$$

Making the assumption that these bounds hold for all buyers, and that the reservation prices are uniformly distributed—the FGC assumption—one can form the average of the bounds gives the average reservation price: $P^R_{i,t} = [P_{i,t} + P_{i,t-1}] / 2$.

Substituting this average price into the Paasche in (3') yields a simple expression that relates that FGC Paasche for new buyers ($\Pi^{NB}_{t,t-1}$) to one constructed using standard methods ($\Pi_{t,t-1}$):

$$(9) \qquad \Pi^{NB}_{t,t-1} = [\ 1/2\ (\ 1 + \Pi_{t,t-1}^{-1}\ )\ ]^{-1}$$

For goods with downward-sloping price contours, the standard Paasche will show price declines ($0 < \Pi_{t,t-1}^{-1} < 1$) and will fall faster than the FGC Paasche: $\Pi_{t,t-1} < \Pi^{NB}_{t,t-1}{}^{-1}$. For example, if the standard Paasche shows a 10% decline ($\Pi_{t,t-1}^{-1} = .9$), the Paasche for new buyers will fall less than that, say 5% ($\Pi^{NB}_{t,t-1} = .95$).

Table 1 illustrates how various degrees of price declines as measured in the standard Paasche (in column 1) translate into the constant-quality price decline experienced by new buyers (column 2). Comparing these two measures shows that the FGC-Paasche for new buyers shows substantially slower price declines than the standard Paasche: these differences range from about 50 to 60 percent of the price declines measured in the standard Paasche. This makes sense because, given the bounds defined above, the average reservation price is about half the distance between the prices used in the standard index.

4.3 Comparison to Conventional Price Measures for Selected High-tech Goods

Using the FGC Paasche as the relevant price measure for one-time purchases, one can compare movements in this index with those of standard indexes to assess the potential numerical importance of this problem. Here, the FGC Paasche is compared to indexes typically reported in the literature as estimates of true price change: superlative indexes like the Fisher and Tornquist indexes or measures obtained from hedonic techniques.

Table 2 uses results reported in the literature to do this comparison. The standard Paasche indexes reported in each study (column 1) were used in (9) to obtain the FGC Paasche indexes (column 2). Comparing these two columns illustrates the theoretical argument made above: declines measured in the FGC Paasche indexes are substantially less than those in the standard Paasche indexes.

Column 3 provides information—either a point estimate or a range—for the preferred indexes reported in the studies. Comparing those estimates with the FGC indexes in column 2 provides some perspective on the potential direction and magnitude of differences in the two indexes of true price change Among the three studies that used Fisher indexes as preferred measures, two of them report Fisher indexes that fall faster than the FGC Paasche: Abel et. al.(2004) and Kokoski et. al.(2000). In these cases, the differences are not trivial: for the Abel et. al. study, price declines in the FGC index were about ½ those in the standard Fisher—declines of 5.2 percent vs. 10.6 percent; for the Kokoski et. al. study, the differences are smaller but still nontrivial—declines of 42 percent vs. 51 percent.

The third study that used a Fisher index—Prudhomme and Yu (2003)—reports a Fisher index that lies *above* the FGC index. This case illustrates that if the gap between the Paasche and Laspeyres is sufficiently wide, the resulting Fisher can lie above the

FGC index. In this case, the gap between the Laspeyres and Paasche was unusually wide: the calculated Laspeyres in this study actually showed price increases and pulled up the Fisher index to a substantially slower price decline than that in the FGC Paasche.

The remaining two studies in table 4 used hedonic techniques as their preferred measure. As may be seen, the hedonic measures fall faster than the FGC index and, again, the differences can be large This comparison is problematic, however, in that the FGC and hedonic measures differ not only in their treatment of new buyers but also in their treatment of new goods. A comparison that would control for this would adopt the strategy proposed by Pakes (2003) for standard indexes and would use reduced-form hedonic regressions to fill in the missing market prices created by new goods before constructing the FGC Paasche index.

On balance, the differences between the FGC and preferred price measures are sufficiently large to suggest that allowing for consumer heterogeneity might be numerically important in the construction of price indexes.

5. Discussion and Future Research

This paper builds on the work in Fisher and Griliches (1995) and Griliches and Cockburn (1994) to define indexes for goods that are purchased only intermittently. For high-tech goods that display downward-sloping price contours, one may bound reservation prices and apply the FGC approach to obtain constant-quality price indexes that allow for the presence of heterogeneous consumers that make one-time purchases. The theoretical discussion above does not provide guidance on when the standard Fisher index will overstate or understate price growth relative to the FGC Paasche or the potential magnitude of those differences. However, calculations based on results reported in the empirical literature found several cases where the reported Fisher indexes fall substantially faster than the FGC Paasche; one can also point to other cases where the two indexes are close or where the Fisher falls less fast than the FGC Paasche.

With regard to the potential applicability of these issues for other durables, as highly disaggregate data become available, the evidence is mounting that durable goods other than high technology goods also have downward-sloping price contours. For example, Corrado, Dunne and Otoo(2003) show that prices for new motor vehicles typically decline over the model year. Similar patterns of price change were found for apparel (Pashigian and Bowen (1991)), television sets (Silver (1999)), consumer audio products (Kokoski et. al. (2001)) and college textbooks (Chevalier and Goolsbee(2004)). It would be interesting to study the price contours for other goods and investigate the possibility that intertemporal price discrimination in the presence of consumer heterogeneity generates those contours. If so, the methods developed here would be relevant for those goods as well.

The FGC approach provides a "fix" for matched-model indexes. Two alternative approaches seem worth pursuing. First, in the context of standard hedonic techniques, one could use household characteristics to control for consumer heterogeneity in a standard hedonic regression. The idea would be that, in addition to controlling for differences in quality across goods, the presence of heterogeneous consumers requires that one also control for differences across households.

The second possibility is to use empirical models of the demand for durable goods that have been recently extended to allow for the presence of heterogeneous consumers who make purchases only intermittently (See, for example, Melnikov(2001), Nair(2002), and Gowrisankaran and Rysman(2005)). Those models implicitly estimate entry and exit probabilities for different groups of consumers and values for their utilities (reservation prices). Those values could be folded into the FGC framework to explore the potential magnitude of the new buyer problem across different durable goods.

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Table 1. Comparison of Standard vs. FGC Paasche Indexes for One-Time Buyers

Standard	FGC
-5	-2.6
-10	-5.3
-15	-8.1
-20	-11.1
-25	-14.3
-30	-17.6
-35	-21.2
-40	-25.0

Table 2. Comparison of FGC Paasche Lower Bound and Preferred Price Measures.

Study	Market	Paasche		Preferred Measure	
		Standard (1)	FGC (2)	Ave % chg (3)	Method (4)
Abel et. al. (2004)	Software	- 9.9	- 5.2	-10.6	Fisher
Cole et. al. (1986)	Printers	- 3.5	- 1.8	-10 to -14	Hedonic
Dulberger (1989)	Processors	- 8.5	- 4.4	-18 to -19	Hedonic
Kokoski et. al. (2000)	CD Players	-58.5	-41.7	-51	Fisher
Prudhomme and Yu (2003)	Software	-24.9	-14.2	-6	Fisher

Source: Author's calculations

Appendix: Comparison of FGC Indexes With Standard Indexes

Comparing the FGC indexes with those constructed under standard methods, the FGC Paasche and the FGC Laspeyres understate and overstate price growth, respectively, relative to the standard indexes. To see this, consider the magnitude of reservation prices relative to market prices. In periods where consumers did not make a purchase, the reservation price is less than the market price. For the Paasche index, replacing the market price in the denominator of a standard index with a (lower) reservation price increases the overall index. So, for example, with falling prices, a standard index that equals .8 (showing a 20 percent price decline) would translate into an FGC index that is greater than that: say, .9 (a 10 percent price decline). A similar argument shows that the standard Laspeyres overstates price growth relative to the FGC Laspeyres.

A simple framework is used here to develop some sense of the potential numerical differences in the standard and FGC indexes. Moreover, because the effect on the Paasche and Laspeyres work in opposite directions, this framework is also used to explore conditions under which the net effect on a Fisher index—an average of the two—is just offsetting.

Beginning with the Paasche, define the units of each good that were sold to continuing buyers as a fixed percentage of the total number of units sold, and simplify the analysis by assuming that this percentage is equal across all goods: $\Sigma_{b\in C} X_i^{\,b} = \gamma^C_{t-1} \Sigma_b X_i^{\,b}$ for all i. Imposing this assumption on (3) yields:

$$(3') \qquad \Pi^{NC}_{t,t-1} = \mathbf{[}\Sigma_i P_{i,t} (\Sigma_b X_{i,t}^{\,b})\mathbf{]} \,/\, \mathbf{[}\, \Sigma_i \, (\Sigma_b X_{i,t}^{\,b}) \, (\gamma^C_{t-1} P_{i,t-1} + (1-\gamma^C_{t-1}) \underline{P}^R_{i,t-1}) \,\mathbf{]}$$

Second, express the average reservation price for new buyers as some fraction of the previous period's market price and, again, assume that this fraction is equal across goods: $P^R_{i,t-1} = \lambda^N P_{i,t-1}$ for all i, with $\lambda^N < 1$ because market prices exceed reservation prices. Substituting this into (3') yields a Paasche index that is a scalar blowup of the unadjusted Paasche index:

$$(3'') \qquad \Pi^{NC}_{t,t-1} = \frac{[\, \Sigma_b \Sigma_i P_i X_{i,t}^{\,b}]}{[\, \Sigma_b \Sigma_i P_{i,t-1} X_{i,t}^{\,b}]} \qquad \frac{1}{(\gamma^C_{t-1} + \lambda^N (1 - \gamma^C_{t-1}))}$$

Because both parameters are positive fractions, the denominator is also a positive fraction ($0 < (\gamma^C_{t-1} + \lambda^N (1 - \gamma^C_{t-1})) < 1$) and the FGC index will take on a higher value--show slower price declines--than the standard index (where the denominator equals 1).

As an example, table 1 uses this expression to illustrate the potential numerical importance of new buyers for a Paasche index that falls about an 84 percent average quarterly percent change at an annual rate--the magnitude of price declines typically seen for microprocessors.[20] Two of the possible values for the parameters yield a scalar of 1 and, thus, return the usual Paasche: one is when the reservation price just equals the

[20] The average quarterly percent changes at an annual rate are calculated as 4 x [($\Sigma\ \Pi_{-1,\,s}$ / S) – 1] x 100).

previous period's market price (the top row of each panel) and the other is when there are no new buyers (the first column).

As one would expect, the FGC Paasche indexes diverge from the standard indexes as one increases the share of new buyers (i.e., reading left to right) or lowers the reservation price (moving down the rows). So, for example, as shown in the top panel, if reservation prices are, on average, about 90 percent of last period's market price, and if about ½ of expenditures on the new good in the current period went to new buyers, then the adjusted Paasche falls about 67 percent per quarter (italics) versus an 84 percent fall for the standard Paasche.

Scanning the table, the range of adjusted indexes is very wide. Because buyers' reservation prices can range from the market price in the previous period to that in the current period, the price change experienced by consumers can range from the value of the standard index to zero (no price change).

A similar exercise yields a Laspeyres index that is a simple multiple of the standard Laspeyres:

$$(4') \qquad \Lambda^{X}_{t,t-1} = \frac{[\, \Sigma_b \Sigma_i P_{i,t} X_{i,t-1}{}^{b}]}{[\, \Sigma_b \Sigma_i P_{i,t-1} X_{i,t-1}{}^{b}]} \quad (\gamma^{C}_{t} + \lambda^{X} (1 - (\gamma^{C}_{t}))$$

where γ^{C}_{t} is the share of unit sales in the current period that were purchased by continuing buyers and λ^{X} is the ratio of the exiting buyers' reservation prices--averaged over buyers--to the market price, assumed constant across goods and buyers. Again, both parameters are positive fractions so the scalar is also a positive fraction. Thus, the FGC Laspeyres index will take on a lower value--show faster price declines--than the standard index.

The FGC Fisher index is the geometric mean of the Paasche and Laspeyres and may be expressed as a multiple of the standard Fisher:

$$(6) \qquad F^{FGC}_{t,t-1} = F^{STD}_{t,t-1} \quad \left[\frac{(\gamma^{C}_{t} + \lambda^{X} (1 - (\gamma^{C}_{t}))}{(\gamma^{C}_{t-1} + \lambda^{N} (1 - \gamma^{C}_{t-1}))} \right]^{1/2}$$

The FGC Fisher index equals the standard Fisher when the second term--call it the adjustment term--equals one and that occurs when the numerator and denominator are equal. A sufficient condition for this to occur is when the gaps between reservation and market prices are the same for new and exiting buyers ($\lambda^{X} = \lambda^{N}$) and when the new buyers' share of unit sales in the current period just equals the exiting buyers' share of unit sales in the base period ($\gamma^{C}_{t} = \gamma^{C}_{t-1}$). Little is known about the magnitude of reservation prices, let alone the magnitude of the gap between reservation and market prices. Suppose for the moment that the gaps are, on average, equal. Then, for growing industries (where entry exceeds exits), one would expect the effect of the Paasche to dominate, in which case the FGC Fisher would take on a larger value--show slower price declines--than the standard Fisher. One would expect the opposite in industries where sales are falling (exits exceed entry).

Table A-1 illustrates this point by providing two examples of calculations of the adjustment term in (6) using different assumptions about continuing buyers' share of unit sales at t-1 (in each row) and time t (in each column). The two panels give calculations when average reservation prices are 95 percent (top panel) and 90 percent (bottom panel) of market prices. Notice that in each table, the numbers on the diagonal are 1, indicating that when markets are neither growing nor shrinking, the FGC Fisher equals the standard Fisher. Numbers for growing markets are given above the diagonal where, as may be seen, the FGC Fisher is a larger number (shows slower price declines) than the standard Fisher. So, for example, if the gap between reservation and market prices is 90 percent, and if the share of unit sales that went to continuing buyers grew from 25 percent at time t-1 to 50 percent at time t, the adjustment factor is 1.04 and a, say, 20 percent decline in the standard index would translate into a 17 percent decline in the FGC index.

In sum, differences between a standard and FGC Fisher index depend on the relative magnitude of new and exiting buyers and on the relative gap between reservation and market prices for new and exiting buyers. So, for example, the analysis suggests that price growth is understated in growing markets and overstated in shrinking markets.

Table A-1. Estimated Ratio of FGC Fisher to Standard Fisher Price

$\mathbf{P^R_s / P_s = .95}$

Percent of unit sales purchased by continuing buyers

At time t-1	At time t				
	0%	25%	50%	75%	100%
0%	0	0.25	0.5	0.75	1
25%	1.00	1.01	1.01	1.02	1.03
50%	0.99	1.00	1.01	1.01	1.02
75%	0.99	0.99	1.00	1.01	1.01
100	0.98	0.99	0.99	1.00	1.01
	0.97	0.98	0.99	0.99	1.00

$\mathbf{P^R_s / P_s = .90}$

Percent of unit sales purchased by continuing buyers

At time t-1	At time t				
	0%	25%	50%	75%	100%
0%	0	0.25	0.5	0.75	1
25%	1.00	1.01	1.03	1.04	1.05
50%	0.99	1.00	1.01	1.03	1.04
75%	0.97	0.99	1.00	1.01	1.03
100	0.96	0.97	0.99	1.00	1.01
	0.95	0.96	0.97	0.99	1.00

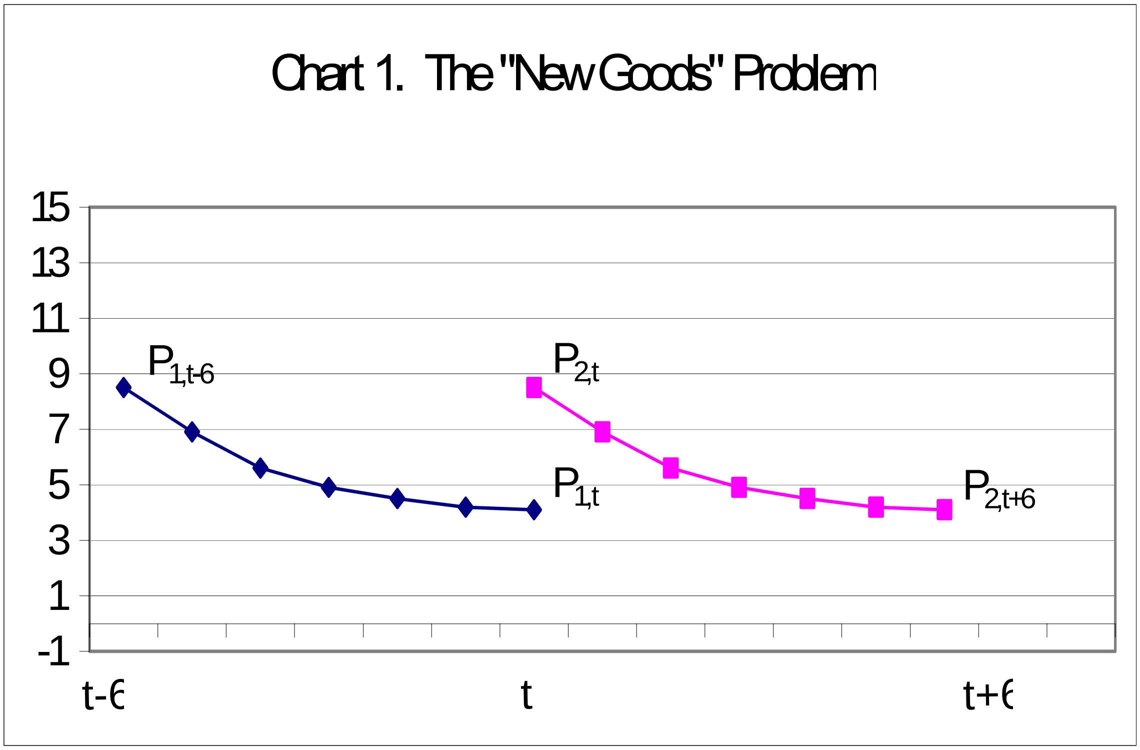
Chart 1. The "New Goods" Problem
15
13
11
9
7
5
3
1
-1
P1,t-6
P2,t
P1,t
P2,t+6
t-6
t
t+6

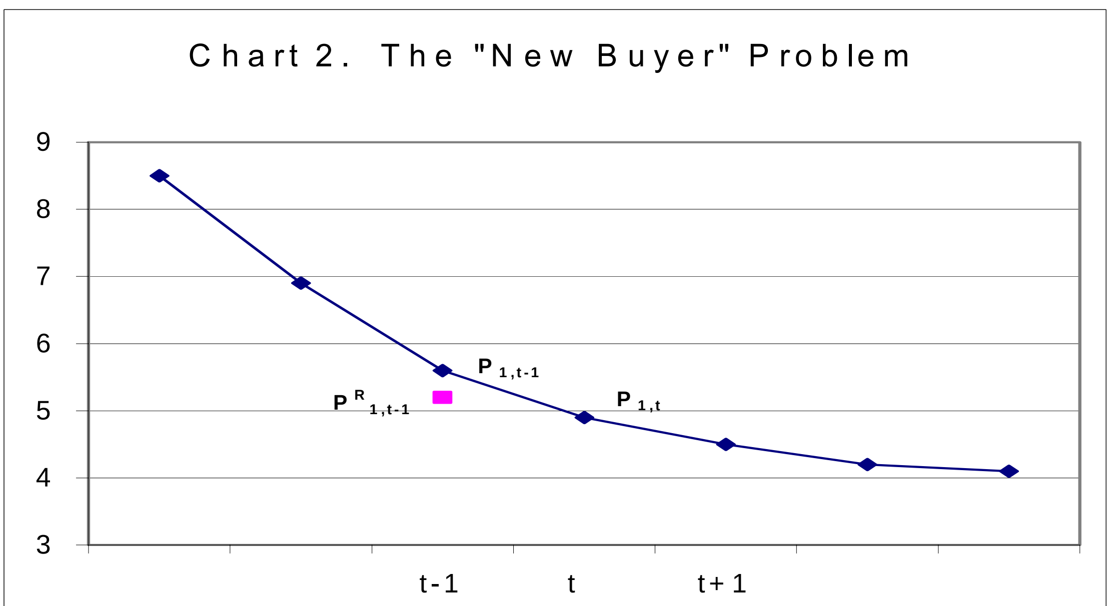
Chart 2. The "New Buyer" Problem
9
8
7
6
5
4
3
P 1,t-1
P R 1,t-1
P 1,t
t-1
t
t+1