Preliminary

Price Indexes for Intermittent Purchases and an Application to Price Deflators for High Technology Goods

Ana Aizcorbe*
Ana.Aizcorbe@bea.gov

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 purchased only intermittently. An algebraic comparison of these indexes to those constructed using standard methods provides conditions under which the two types of indexes are likely to might be numerically close. An empirical application to the case of high technology goods suggests that the price declines reported in the literature may overstate the true underlying rate of technological innovation, though one can find cases where it appears to work in the opposite direction. Further research is needed to pin this down further and to assess the numerical magnitude of this potential problem.

* Office of the Director, Bureau of Economic Analysis, 1441 L Street, NW, Washington, DC 20005. This paper benefited from comments from Jason Cummins, Mark Doms, Joe Gagnon, David Lebow, Marshall Reinsdorf, Jack Triplett and workshop participants at the Brookings Institution and the Federal Reserve Board. The views expressed here are mine alone and do not represent views of staff members at the Bureau of Economic Analysis.

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 suggested by Fisher and Griliches (1995) and Griliches and Cockburn (1995) (hereafter, FGC) for what one might call the "new buyer" problem in prescription pharmaceuticals.

---

[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?"

This paper builds on work by FGC and develops price indexes for goods that are purchased intermittently. In that case, indexes must account for the presence of new, continuing and exiting buyers. The FGC-type indexes developed here are then applied to the case of high technology goods, a class of durable goods with important macroeconomic implications.

The paper has two main findings. First, the paper finds a set of sufficient conditions under which a standard Fisher index is consistent with one that allows for intermittent purchases. Briefly, those conditions are that 1) the market that is under investigation is such that consumers remain "in the market" after making a purchase, 2) the gap between market prices and the average reservation price for new buyers is roughly the same as that for exiting buyers, and 3) the market is stable in that the number of goods sold to entrants equals that sold to exiting buyers. Under these conditions, the standard Paasche index shows faster price declines than the FGC Paasche, the standard Laspeyres shows slower price declines than the FGC Laspeyres and the standard Fisher index—an average of the standard Paasche and Laspeyres indexes—gives a close approximation to the FGC Fisher index.

It is argued that these conditions--though useful for fixing thoughts--are not likely to hold for many durable goods. In particular, consumer purchases of these goods tend to be one-time purchases where consumers leave the market once the purchase is made. With one-time purchases, the FGC Laspeyres and Fisher indexes are undefined because reservation prices do not exist for exiting consumers. However, the Paasche index does give a measure of pure price change in that it controls for changes in buyers' valuations of existing goods over the time period.

Using the FGC Paasche as the "true" measure of price change, numerical calculations done for several high technology goods suggest that the FGC Paasche can, in principle, fall slower *or* faster than indexes constructed under standard methods. This stands in contrast to the finding in Hobijn (2002) that standard price indexes will always overstate the rate of true price declines.[4]

[4] Hobijn(2002) compared indexes of the type constructed by BLS to a theoretically correct price index for a representative consumer facing CES preferences and reached the same conclusion. He argues that the culprit is markups while this paper argues that it is consumer heterogeneity.

An empirical exploration suggests that numerical differences between the FGC and standard indexes may be nontrivial, suggesting that there may be potentially important implications for economic growth and productivity in the macroeconomy. As such, this paper contributes to a large and growing strand of the price measurement literature that is concerned with the ability of standard measures to provide accurate measures of technological change and product innovation for high technology goods.[5]

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.[6] Because this framework forms the basis for what follows, this section reviews the problem and how standard solutions split out quality change from pure price change.

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:

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

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.[7]

---

[5] 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(2002). More recently, Feenstra and Knittel (2004) explore these issues in the context of hedonic regression analysis.

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

[7] 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.

Chart 1 illustrates this “new goods” problem and the “reservation price” solution in the context of the downward-sloping price contours that are characteristic of many high technology goods[8] and perhaps other goods as well.[9] Assume that the models in chart 1 are defined such that quality is constant over the life of the good so that quality 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 if 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 is a measure of his valuation of the quality improvement in the new good at t-1.[10]

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

[8] Prescription drugs are one important exception (Griliches and Cockburn (1994).

[9] The shape of these profiles for DRAM memory chips are discussed in Flamm(1989) and Irwin and Klenow(1994) for DRAM chips and for microprocessor chips in Aizcorbe (2002). With regard to other goods, 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)) and for consumer audio products (Kokoski et al (2000)).

[10] 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: $(P_{2,t+1}/P_{1,t-1}) / [(P_{2,t+1}/ P_{2,t})(P_{1,t}/ P_{1,t-1})(P_{2,t}/ P^R_{2,t-1})] = (P^R_{2,t-1}/P_{1,t-1})^{½} (P_{2,t}/P_{1,t})^{½}$

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 need a reservation price for the exiting model.

3. Indexes for Intermittent Purchases

When consumers do not purchase goods every period, price indexes must take into account the presence of new and exiting buyers. FGC 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; that resulting index is then combined with the FGC Paasche to form a Fisher Index.

This section reviews the construction of these FGC-type indexes and identifies the conditions necessary for them to equal standard indexes.

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. 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 summations are over buyers, b, and goods, i; $b\in C$ and $b\in N$ denote continuing and new buyers, respectively; and "NC" denotes that the Paasche index measures price change for new and continuing buyers. 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 and the market basket for new buyers using their (individual) reservation prices. Note that although market prices do not vary over buyers, reservation prices are buyer-specific.

Second, they propose a way to deal with unobserved reservation prices. 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 $\underset{\sim}{\mathbf{P}}^{R}_{i,t-1} = [\Sigma_{b\in N} P^{R,b}_{i,t-1} X_{i,t}^{b}] \ / \ [\Sigma_{b\in N} X_{i,t}^{b}\ ]$. While the numerator is unchanged—it always measures nominal expenditures in the current period—the denominator now uses an average of consumers' reservation prices to evaluate units purchased by new buyers in the current period.

Finally, to measure the 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, one can calculate the average reservation price as the average of the bounds. In their application, the market prices for the branded and generic drugs provided a natural way to bound reservation prices.

Thus, if one can place bounds on reservation prices, one can use the FGC approach to construct a Paasche index that explicitly accounts for the presence of new buyers.[11]

3.2 The FGC Laspeyres and Fisher Indexes

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:[12]

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

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:

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

Briefly, FGC show that while cost of living indexes (COLI) have traditionally been theoretically justified within the representative consumer paradigm, these indexes have a COLI interpretation even when consumers are heterogeneous. The Paasche index was traditionally interpreted as a lower bound for a *representative* consumer's COLI, where the COLI is the minimum amount of income one would have to give the representative consumer to make him indifferent between purchasing current quantitites at prices in the base and current periods. In contrast, FGC define a set of "true" aggregate cost of living indexes for an ideal social planner that are analogous to the standard COLIs and are defined as the minimum total expenditure a social planner would need to spread across individual buyers in order to leave each buyer indifferent between prices in the base and current periods.

This interpretation is problematic for durable goods. In that case, the relevant metric for consumer welfare is a measure that acknowledges the durability of the good—a rental or user cost. However, such an index can only be used as a deflator for industry output under strong assumptions—for example, if changes in user costs equal changes in acquisition prices.

[12] 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.

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

3.3 Comparisons With Standard Indexes

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

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:

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

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.[13] 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 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).

---

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

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:

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

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 2 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.

4. An Application to High Technology Goods

An application of this framework to high technology goods raises two issues with potential implications for price measurement.[14] First, consumer purchases of durable goods in the high-technology sector—particularly the large-ticket items like computers—are likely to be one-time purchases. The implication for price measurement is that there are no continuing buyers—all buyers are either new or exiting buyers—and the Paasche index measures price change for new buyers only.

The Laspeyres index would measure price change for exiting buyers if exiting buyers had a well-defined reservation price in the period after making a purchase. For

[14] The fact that high tech goods tend to be durable goods raises an unresolved price measurement problem. In particular, the relevant metric for consumer welfare is a measure that acknowledges the durability of the good—a rental or user cost. However, in practice, the paucity of data with which to construct such indexes has led many to construct simple indexes based on acquisition prices. To construct a deflator for industry output (rather than a consumer price index), it would seem that acquisition prices are the relevant metric and that is the view taken in this paper. The problem is resolved under the (strong) assumption that changes in acquisition prices track those of user costs.

exiting buyers, however, it's not clear that a reservation price exists. Take, for example, a very durable good—like a house. It's hard to imagine a price sufficiently low to persuade a buyer to purchase a second home in the period following the purchase of his first home. In this sense, one could argue that a reservation price is "not well defined" or "doesn't exist" in periods closely following a purchase.[15]

Absent a well-defined reservation price for exiting buyers, and if all consumers are one-time buyers, price relatives for new buyers provide a measure of changes in quality as valued by the only buyers that were "in the market" in both periods. That is, given reservation prices for new buyers, a Paasche index provides a measure of "pure price change" for the only consumers that were "in the market" both periods. Thus, the Paasche index provides a best guess at pure price change.[16]

4.1 Paasche Index for One-time Purchases of High Tech Goods

The challenge in constructing these indexes is in finding ways to measure 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.

In a dynamic setting, "reservation prices" may be viewed as the present discounted value of the future stream of net benefits of purchasing today. Suppose that reservation prices are falling over time either because there are costs to waiting or because buyers are impatient.[17] Then, the optimal rule for buyers is to purchase the good when the market price dips below his reservation price. Once the purchase is made, the consumer leaves the market.

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

[16] 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.

[17] For example, if potential buyers are in the market to replace a durable good, their reservation prices could fall over time if there are costs to waiting--maintenance, increasing risk of scrappage. Similarly, if buyers have a strong preference for newness, their willingness to pay will fall as new models age.

This paper exploits the downward-sloping nature of price contours for many high technology goods to obtain bounds for consumers' reservation prices and uses those bounds to form FGC indexes for these goods. These shape of these contours may be generated by cost- or demand-side factors. For example, two studies that examined these contours for memory chips (DRAM)—Irwin and Klenow (1994) and Flamm (1996)—argue that it is likely that contours for DRAM chips are generated cost-side factors. In particular, the production of memory chips involves a steep learning curve that lowers average cost over the life of the chip. Because DRAM markets are highly competitive, these sharp reduction in costs is likely translated into rapidly falling prices.

An example of a market where demand-side conditions likely play a major role in generating these contours is the microprocessor market. As discussed in Aizcorbe (2003), this market is highly concentrated—Intel's market share was above 80 percent over much of the 1990s—and Intel's markups are quite high. Moreover, industry estimates suggest that these markups decline rapidly over the life of the microprocessor—average costs range between $25-100 while prices fall from around $700 at introduction to around $100 at the end of the chip's life.

For microprocessors, the contours likely arise because purchases over the life of a good are made by different, heterogeneous buyers. Facing heterogeneous consumers, Intel might find that an intertemporal discrimination pricing strategy maximizes profits.[18] A full discussion of this type of "price skimming" as a pricing strategy for new goods is given in Dean (1969):

> "Launching a new product with a high price is an efficient device for breaking the market up into segments that differ in price elasticity of demand. The initial high price serves to skim the cream of the market that is relatively insensitive to price. Subsequent price reductions tap successively more elastic sectors of the market. This pricing strategy is exemplified by the

[18] There is an argument that a durable-goods monopolist is not likely to undertake this strategy. In particular, Coase has argued that, under certain conditions, a durable goods monopolist will tend to expand production to where price equals marginal cost because it is, in effect competing with the future incarnation of itself. However, to the extent that capacity constraints effectively limit the expansion of output, the Coase conjecture will not hold (McAfee and Wiseman(2004)). If the steep learning curve faced by semiconductor producers serves as a capacity constraint (Flamm (1989), then one could argue that the Coase conjecture does not apply for microprocessors or other markets that operate under similar conditions.

> systematic succession of editions of a book, sometimes starting with a \$50 limited personal edition and ending up with a 25-cent pocket book." (P. 174)

In either case, these downward-sloping price contours may be used to obtain bounds for consumers' reservation prices. Chart 2 traces out a typical price contour, where a new good enters the market at time t-3. 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 prices 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, 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. 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. If his reservation price fell over the period, then the observed prices in the two periods provide bounds for his reservation price. That is,

$$(7) \qquad P_{i,t} < P^R_{i,t} < P^R_{i,t-1} < P_{i,t-1} \ ,$$

Assuming these bounds hold for all buyers, one can form the average of the bounds to obtain the FGC reservation price: $P^R_{i,t} = [P_{i,t} + P_{i,t-1}] / 2$.

This average reservation price may be used in the FGC Paasche index to obtain a Paasche for high tech goods that allows for the presence of new buyers. If all buyers are new buyers, the Paasche in (3) reduces to the following Paasche for new buyers:

$$(8) \qquad \Pi^{NB}_{t,t-1} = [\Sigma_i P_{i,t} (\Sigma_b X_{i,t}{}^b)] \ / \ [\Sigma_i \mathbf{P}^R_{i,t-1}(\Sigma_{b\in N} X_{i,t}{}^b)].$$

That assumption and the expression for the average reservation price given in FGC may be applied to (8) to obtain 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 falls 10% ($\Pi_{t,t-1}^{-1} = .9$), the Paasche for new buyers will fall less than that, say 5% ($\Pi^{NB}_{t,t-1} = .95$).

Table 3 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.

<u>4.2 Comparison to Conventional Price Measures for High Tech Goods</u>

If one views the FGC Paasche as the relevant price measure for one-time purchases, then it would be useful to know how movements in this index compare with those of standard indexes. Although the discussion above pins down the relationship between the FGC and standard Paasche measures, no one views the standard Paasche as a "true" measure of price change. Instead, the relevant comparison is between the FGC Paasche and indexes typically reported in the literature as estimates of true price change: Fisher and Tornquist indexes or measures obtained from hedonic techniques.

Table 4 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 For 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 (2000). The third study--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 the FGC Paasche.

The remaining two studies in table 4 used hedonic techniques to obtain their preferred measures. As may be seen, the hedonic measures fall faster than the FGCindex. This comparison is problematic, however, in that the FGC and hedonic measures are based on different cuts of the data: matched model indexes only include observations where prices exist for both periods whereas hedonic techniques use all observations. To level the playing field, one could adopt the strategy proposed by Pakes (2003) and use reduced-form hedonic regressions to fill in the missing market prices before constructing the FGC Paasche index.

5. Discussion and Implications

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. The analysis shows that a standard Paasche index will tend to show faster price declines than the FGC Paasche that explicitly allows for the presence of new buyers. Similarly, a standard Laspeyres index will fall slower than the FGC Laspeyres. Under certain conditions, the standard Fisher index—an average of the Laspeyres and Paasche—can be numerically close to a Fisher index that accounts for buyer turnover.

Two of the required conditions are not likely to hold for high technology goods. First, the condition that markets be stable does not hold in a rapidly-growing sectors like the high-tech sector. And, second, the condition that reservation prices be well-defined for consumers is not likely to hold in this sector because these purchases tend to be one-time purchases where consumers likely leave the market once the purchase is made. The implication for measurement is that a reservation price for exiting buyers does not exist and the Laspeyres and Fisher indexes are undefined. The remaining index—the FGC Paasche—is the only one that can use information from consumers that were in the market both periods. It is viewed as a "matched-buyer" index and is used as the best guess for pure price change.

Consistent with the theoretical analysis, rough calculations that compare price declines exhibited by the FGC Paasche with those of a Paasche constructed under standard methods suggests that standard methods will understate constant-quality price declines and, thus, work in the direction of overstating quality improvements for high tech goods. Little may be said about the potential magnitude of the overstatement, however, and further work is needed to explore this issue.

The FGC Paasche index was also compared to preferred measures like the Fisher index or indexes based on hedonic techniques. 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. Calculations based on results reported in the empirical literature is mixed; while one can find cases where 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.

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), Abel, Berndt and White (2003))

There remains an important role for hedonics, however. A well-known problem with matched-model methods is that available datasets often do not contain sufficient matches (overlap) to use a large percentage of the observations, in which case the index is based only on a (possibly small) subset of the observations. Nonetheless, for datasets with missing prices, the FGC technique may still be used if predicted values from hedonic regressions are used as proxies for the missing prices—a method called the "imputation method" by Triplett (1990) and recently advocated by Pakes (2003).

REFERENCES

Abel, J., E. Berndt and A. White (2004) “Price Indexes for Microsoft’s Personal Computer Software Products,” NBER Working Paper No. 9966, March.

Aizcorbe, Ana (2002) "Why Are Semiconductor Prices Falling So Fast?" FEDS Working Paper 2002-20,

Aizcorbe, A., C. Corrado and M. Doms (2000) "Constructing Price Indexes for High Technology Goods," Available at www.nber.org.

Anderson, S.P., dePalma, A. and Thisse, J. (1992) *The discrete choice theory of product differentiation*. Cambridge, MA: MIT Press.

Berndt, E. R. and Zvi Griliches, “Price Indexes for Microcomputers: An Exploratory Study,” in *Price Measurements and Their Uses*, ed. Murray Foss, Marilyn Manser, and Allan Young. (Chicago: The University of Chicago Press, 1993), pp. 63-93.

Berndt, E.R., Z. Griliches and N. Rappaport (1995) “Econometric Estimates of Price Indexes for Personal Computers in the 1990s,” *Journal of Econometrics*, 68:243-268.

Betancourt, Roger R., and David Gautschi (1992) ‘‘The Demand for Retail Products and the Household Production Model: New Views on Complementarity and Substitution,’’ *Journal of Economic Behavior and Organization,* 17, 257-275.

Coase, Ronald (1972) "Durability and Monopoly," *Journal of Law and Economics* 15, Pp. 143-149.

Cole, Rosanne, Y.C. Chen, Joan A. Barquin-Stolleman, Ellen Dulberger, Nurhan Helvacian, and James H. Hodge (1986) “Quality-Adjusted Price Indexes for Computer Processors and Selected Peripheral Equipment,” *Survey of Current Business 66* (January), pp. 41-50.

Corrado, Otoo and Dunn (2003) An Initial Look at Incentives and Prices for Motor Vehicles: What Has Been Happening in Recent Years? Paper presented at the CRIW/NBER Summer Institute, July 28.

Dean, J. (1969) “Pricing Pioneering Products,” Journal of Industrial Economics, 17(3):165-179.

Diewert, W.E. (1995) "Axiomatic and Economic Approaches to Elementary Price Indexes" Discussion Paper Nol. 95-01, Department of Economics, University of British Columbia.

Dulberger, E.R. (1989) "The Application of a Hedonic Model to a Quality-Adjusted Price Index for Computer Processors," in *Technology and Capital Formation*, ed. Dale Jorgenson and Ralph Landau. Cambridge, Mass.: MIT Press.

Dulberger, E.R. (1993) "Sources Of Price Decline In Computer Processors: Selected Electronic Components," in *Price Measurements and Their Uses* , ed. Foss, Murray F., Marilyn E. Manser, and Allan H. Young. Cambridge, Mass.: MIT Press.

Feenstra, R. C. (1995) "Exact Hedonic Price Indexes," *Review of Economics and Statistics*, 77(4):634-53, November.

Feenstra, R.C. and Knittel, C. (2004) "Re-Assessing the U.S. Quality Adjustment to Computer Prices: The Role of Durability and Changing Software," Paper presented at the CRIW Conference on Price Index Concepts and Measurement, Vancouver, BC, Canada, June 29.

Feenstra, R.C. and M. Shapiro (2000) High-Frequency Substitution and the Measurement of Price Indexes, Paper presented at the CRIW conference ''Scanner Data and Price Indexes,'' Sept. 15-16, 2000, Washington, DC.

Fisher, F. and Z. Griliches (1995) "Aggregate Price Indices, New Goods, and Generics," *Quarterly Journal of Economics*, 229-44, February.

Fisher, F.M. and K. Shell. (1972) "Taste and Quality Change in the Pure Theory of the True-Cost-of-Living Index," in Z. Griliches, ed. *Price Indexes and Quality Change.* Cambridge, Mass.: Harvard University Press, Pp. 16-54.

Flamm, K. (1996) *Mismanaged Trade? Strategic Policy and the Semiconductor Industry,* Washington, D.C.: Brookings Institution.

Flamm, K. (2003) "Moore's Law and the Economics of Semiconductor Price Trends" (paper presented to the National Research Council Symposium on Productivity and Cyclicality in Semiconductors: Trends, Implications, and Questions, Kennedy School of Government, Harvard University, Cambridge, Mass., September 24, 2001; updated draft, December 2001).

Gordon, R. (2000) "Does the New Economy Measure Up to the Great Inventions of the Past?" NBER Working Paper No. 7833, August. Available at: http://papers.nber.org/papers/W7833

Griliches, Z. and I. Cockburn (1994) "Generics and New Goods in Pharmaceutical Price Indexes," *American Economic Review* 84(5):1213-1232.

Grimm, B. T. (1998) "Price Indexes for Selected Semiconductors, 1974-96," *Survey of Current Business*, February.

Hall, Robert E. and Dale W. Jorgenson. 1967. "Tax Policy and Investment Behavior." *American Economic Review*, 57, No. 3 (June): 391-414.

Hendel, I. and A. Nevo (2002) "Measuring the Implications of Sales and Consumer Stockpiling Behavior," mimeo.

Hicks, J.R. (1940) "The Valuation of Social Income," *Economica*, VII, Pp. 105-24.

Irwin, D. A. and P. Klenow (1994) "Learning by Doing Spillovers in the Semiconductor Industry," *Journal of Political Economy*, 102(6):1200-1227, December.

Jorgenson, D.W. (2000) "Information Technology and the U.S. Economy," *Presidential Address to the American Economic Association*, New Orleans, Louisiana, January 6.

Kokoski, M., K. Waehrer and P. Rozaklis (2001) "Using Hedonic Methods for Quality Adjustment in the CPI: The Consumer Audio Products Component" BLS Working Paper No. 344, Office of Prices and Living Conditions, March.

McAfee, R. P. and T. Wiseman Capacity Choice Counters the Coase Conjecture, mimeo available at http://www.gsb.stanford.edu/facseminars/events/economics/pdfs/CoaseApr2003.pdf

National Academy of Sciences, *At What Price*

Oliner, S. and D. Sichel (2000) "The Resurgence of Growth in the Late 1990s: Is Information Technology the Story?" *Journal of Economic Perspectives*, 14(4):3-22.

Pakes, A. (2003) ''A Reconsideration of Hedonic Price Indices with an Application to PC's,'' *American Economic Review*, Vol: 93 (5) pp. 1578 - 1596.

Pashigian, B. P and B. Bowen (1991) "Why are products sold on sale? Explanations of Pricing Regularities." *Quarterly Journal of Economics*, 106(4):1015-1038.

Prud'homme, M. and K. Yu (2003) "A Price Index for Computer Software Using Scanner Data" Paper presented at the Brookings Institution workshop on Economic Measurement, May 23.

Reinsdorf, M. (1993) "The Effect of Outlet Price Differentials in the US Consumer Price Index," in M.F. Foss, M.E. Manser, and A.H.Young, eds. *Price Measurements and Their Use*, Chicago, Ill: University of Chicago Press, Pp. 227-254.

Rosen, S. (1974) "Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition, *Journal of Political Economy*, Pp. 34-55.

Silver, M.S. (1999) "Disparities in the prices of new and old models when they coexist in the market: some econometric estimates," *International Journal of Management Science* 27(1999): 13-24.

Triplett, Jack (1990) "Hedonic methods in statistical agency environments: an intellectual biopsy," in Berndt, E.R., and J.E. Triplett (eds.) *Fifty years of economic measurement: the Jubilee Conference on Research in Income and Wealth,* NBER Studies in Income and Wealth, Chicago: University of Chicago Press.

Triplett, J. (1998) "The Solow Productivity Paradox: What Do Computers Do to Productivity?" *Canadian Journal of Economics*, Volume 32, No. 2, April 1999. p. 319. Available at http://www.csls.ca/jrn/v32n2_04.pdf.

Table 1. FGC Paasche Lower Bound for Intel's Microprocessors, 93-99

Reservation Price (percent of P_{t-1})	Percent of unit sales that went to new buyers 0%	25%	50%	75%	100%
quarterly percent change at an annual rate					
100%	-84.0	-84.0	-84.0	-84.0	-84.0
99%	-84.0	-83.2	-82.4	-81.6	-80.8
95%	-84.0	-80.0	-75.9	-71.7	-67.4
90%	-84.0	-75.9	-67.4	-58.4	-48.9
85%	-84.0	-71.7	-58.4	-43.9	-28.2
80%	-84.0	-67.4	-48.9	-28.2	-5.0

Source: Author’s calculations

Table 2. Estimated Ratio of FGC Fisher to Standard Fisher Price

$$P^{R}_{s} / P_{s} = .95$$

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

$$P^{R}_{s} / P_{s} = .90$$

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

Table 3. 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 4. Comparison of FGC Paasche Lower Bound and Preferred Price Measures.

		Paasche		Preferred Measure	
Study	Market	Std.	FGC	Ave % chg	Method
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

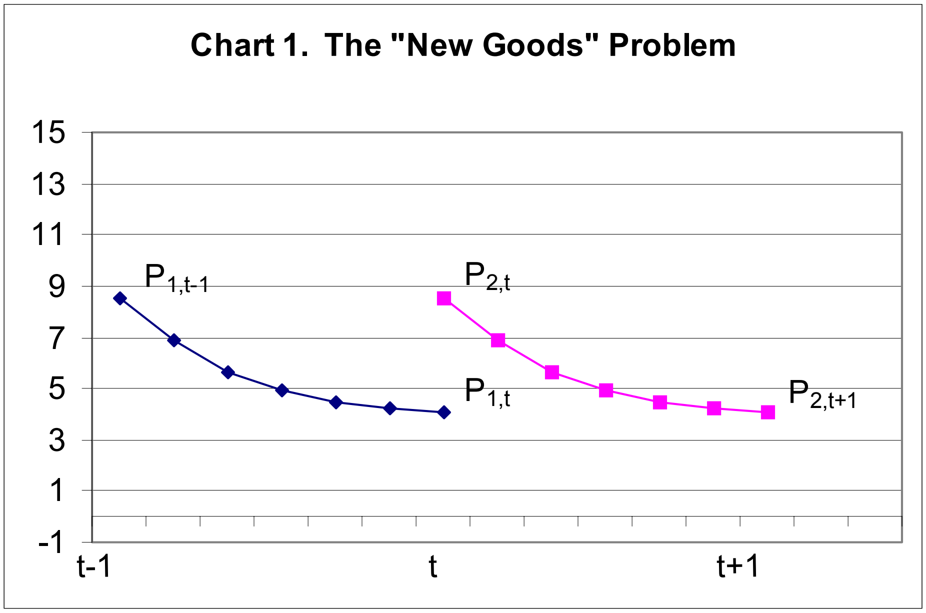
Chart 1. The "New Goods" Problem
15
13
11
9
7
5
3
1
-1
t-1
t
t+1
P1,t-1
P2,t
P1,t
P2,t+1

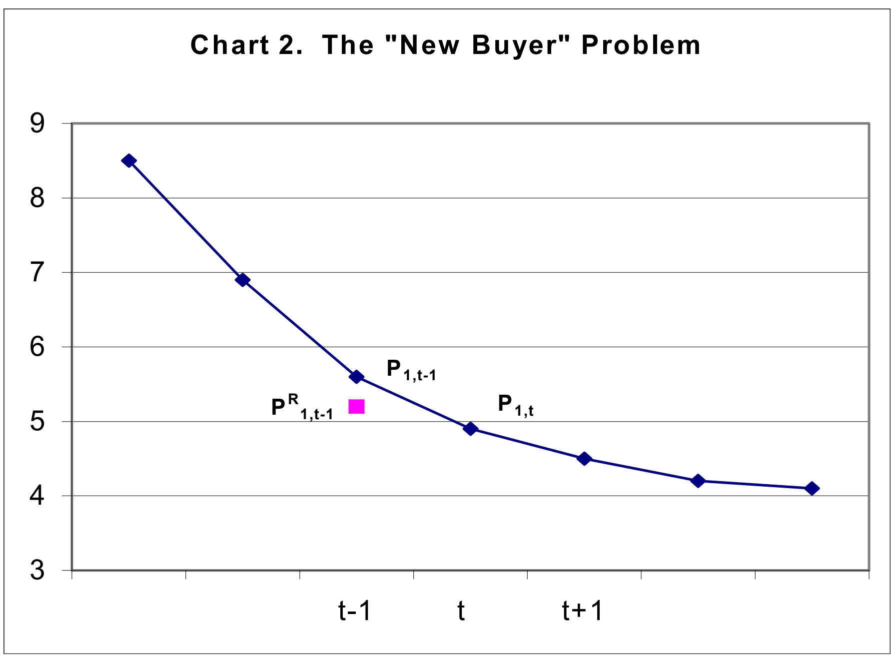
Chart 2. The "New Buyer" Problem
9
8
7
6
5
4
3
t-1
t
t+1
P1,t-1
PR1,t-1
P1,t