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Abstract

We define a class of bias problems that arise when purchasers shift their expenditures among sellers charging different prices for units of precisely defined and interchangeable product items that are nevertheless regarded as different for the purposes of price measurement. For business-to-business transactions, these shifts can cause *sourcing substitution bias* in the Producer Price Index (PPI) and the Import Price Index (MPI), as well as potentially in the proposed new true Input Price Index (IPI). Similarly, when consumers shift their expenditures for the same products temporally to take advantage of promotional sales or among retailers charging different per unit prices, this can cause a *promotions bias problem* in the Consumer Price Index (CPI) or a CPI *outlet substitution bias*. We recommend alternatives to conventional price indexes that make use of unit values over precisely defined and interchangeable product items. We argue that our proposed ideal target indexes could greatly reduce these biases and make use of increasingly available electronic scanner data on prices and quantities. We also address the challenges national statistics agencies must surmount to produce price index measures more like the specified target ones.

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1. Introduction

Price indexes are fundamentally important for understanding what is happening to national economies. Unfortunately, for reasons we explain, price index bias problems seem likely to have grown with the evolution of information technologies and accompanying changes in business price-setting and product variant development practices, as well as with the growth in the amount and timeliness of price information available to potential buyers. We argue, however, that specific changes to statistics agency practices and data handling capabilities can greatly reduce the bias problems we focus on.

We recommend alternatives to the conventional price indexes. The alternative indexes use unit values to combine transactions that take place at different prices for homogeneous product units.[2] They reduce to the conventional price indexes when there is truly just one price per product for each time period. This recommendation is in line with the advice provided in several international price index manuals (e.g., ILO et al. 2004a, 2004b and 2009). For example, the manual for the Producer Price Index (PPI) states:

> [H]aving specified the product to be priced..., data should be collected on both the value of the total sales in a particular month and the total quantities sold in order to derive a unit value to be used as the price…. (ILO et al., 2004a, para. 9.71)[3]

Some of the prices used in a typical PPI are calculated in this way, yet as a rule, the conventional statistical agency practice does not measure prices as unit values.[4] The conventional practice of national statistics agencies is to collect the price of a precisely defined product at a particular

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[2] We are not referring here to units of different size for the same type of product such as milk of the same sort from the same producer but sold in different-sized cartons. We consider those to be different products, just as they would be designated by different Universal Product Codes in the records of a business. Note also that we are *not* using the term *unit value* to mean the price per some set unit of weight or volume (like the price per ounce). Rather, we are using the term to mean the average price per unit of a product as it is sold (e.g., the price per box or bag). In other words, we are using the term "unit" as it is used in the official statistics literature rather than adopting the term "item" used for the same thing in the world of commerce. Using the term "item" would ease the problems of interacting with the business community and business information data systems and would avoid confusion with the "unit price" that grocers in many jurisdictions are required by law to display for all their products, but it would make the paper harder to read for the official statistics community, which is where we are trying to gain support for our reform proposals first.

[3] http://www.ilo.org/public/english/bureau/stat/download/cpi/corrections/chapter9.pdf

[4] Statistical agencies with practices more in line with our recommendation are noted in Section 7. In addition to those agencies, many countries use monthly unit values for some of the prices used to compile their PPIs.

establishment and designated point in time, with this collection process being designed to yield a unique price each period for the given product-establishment combination.[5]

Section 2 introduces the issues. Section 3 provides notation and definitions used in the rest of the paper. The Laspeyres, Paasche, and Fisher price index formulas are introduced in the basic forms in which these are usually presented in textbooks and in the economics, accounting, and price index scholarly literature. Next we develop hybrid price index formulas that explicitly allow for possible price differences in a given time period for homogeneous units of each product. A form of the unit value with grouped transactions allows us to represent various biases that can result from the use of a single price observation per product-establishment cell to estimate inflation when transactions take place at multiple prices.

In Section 4, we use our bias formula for a Laspeyres-type price index to characterize sources of price index bias that arise because of the conventional practices for collecting and using price quote versus value share data. The biases discussed include the recognized problem of CPI outlet substitution bias,[6] the CPI promotions bias defined in this paper, and what Diewert and Nakamura (2010/2011) define as sourcing substitution bias in the PPI and MPI.[7] We deal briefly as well with sourcing bias in the proposed new IPI.

The Bureau of Labor Statistics (BLS) of the United States produces the price indexes we focus on in this paper. The BLS largely abandoned the use of unit values in price index compilation because of advice from experts, including the 1961 report of the Stigler Committee, and research by its own staff (exemplified by Alterman, 1991).[8] In Section 5, we examine the problems with unit values that are highlighted in the Stigler Committee report and by Alterman (1991). We explain why the main basis of condemnation in those historical reports does not pertain to our present unit value recommendation.

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[5] See, for example, the Bureau of Labor Statistics (2007a-2007/2013).

[6] Reinsdorf (1993) and Diewert (1995/2012, 1998) defined and brought attention to this price index bias problem. For related materials, see Greenlees and McClelland (2011), Moulton (1993, 1996a, 1996b), Reinsdorf (1994a, 1994b, 1994c, 1999a, 1999b), Reinsdorf and Moulton (1997), and Nakamura (1999), Hausman (2003), and White (2000).

[7] Diewert and Nakamura (2010/2011) define this bias problem and provide a measurement formula for it, having been inspired to work on this problem by the arguments and empirical evidence of Houseman (2007, 2009, 2010, 2011) and Mandel (2007, 2009). See also Houseman et al. (2011), Inklaar (2012), and Fukao and Arai (2013).

[8] Price Statistics Review Committee (1961). Reinsdorf and Triplett (2009) review the context and content of the Stigler Committee's recommendations.

Nevertheless, there are formidable practical challenges to implementing unit values as we recommend. Producers give their products identifying names and product numbers. In particular, most producers give their products identifiers called Universal Product Codes (UPCs). UPCs have come to play a fundamentally important role in business information systems and in product unit tracking in business inventory, transportation, and supply chain management systems. UPCs are assigned and printed on product unit packaging by producers in conformity with internationally agreed upon rules and guidelines. For example, once a 10.75-ounce can of Campbell's tomato soup is shipped out from the production facility carrying the UPC that Campbell's has assigned to that product, then that UPC stays with that soup can wherever it goes.

However, along the way from the original producer to the final purchaser, a unit of a product can take on auxiliary attributes that may matter to the final purchaser and may be associated with price differences. For example, some of the cans of tomato soup may be shipped by the producer to convenience stores, and some may be shipped to superstores.

On the other hand, UPCs are often defined at too fine a level of detail to keep all the products with functionally identical physical characteristics together, making it necessary to aggregate some UPCs as we discuss in Sections 5.3 and 5.4 (see also Reinsdorf, 1999b). A producer might bring out a slightly reformulated product with a different UPC and with a price that yields a higher profit margin.[9] If the quality change is trivial, the reformulated version of the product should be treated as a continuation of the original version so that the price increase can be captured. Moreover, some products with different UPCs are nearly, or even totally, identical in their physical attributes despite coming from different producers.

How, then, can we best measure price change over time when units of precisely defined and interchangeable product items are sold at different prices in the same time period and market area, and sometimes even by the same business? And when is it best to treat highly similar but commercially distinguishable products as separate products for inflation measurement purposes? Consideration of these questions requires an understanding of the role that measures of inflation play in the compilation of other key economic performance measures for nations: This is the topic of Section 6. Finally, in Section 7, we suggest possible changes to conventional price index making practices.

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[9] See Nakamura and Steinsson (2008, 2012) for more on this sort of "price flexibility" and its significance for understanding and for the management of inflationary pressures in the macroeconomy.

Two brief appendices provide additional materials that some readers may find helpful. In appendix A, we show with a numerical example that the featured bias problem in the example cannot be fixed simply by adopting a superlative price index formula like the Fisher.[10] Appendix B demonstrates why, ideally, the same product definitions should be used for both the price quote collection and for the collection of the data needed to compute value share weights.

This paper is written with three different groups of readers in mind. One group consists of those who view unit averaging all observable prices to form unit values as an inferior practice. We hope to persuade these readers that for a wide class of price index uses, including the deflation of gross domestic product (GDP) components, it is important that the price quotes utilized are representative of the prices for the transactions that make up the associated value aggregates.

A second group we hope will benefit from this paper are those who were already convinced by what early contributors to the price index literature — Walsh (1901, p. 96; 1921, p. 88), Davies (1924, p. 183; 1932, p. 59), and Fisher (1922, p. 318), in particular — wrote long ago on the use of unit values in price indexes. These are experts who hold the view that there is no need to elaborate on the issues we deal with in this paper. We hope to persuade these readers that there is considerable value in having a more explicit exposition of these issues. We hope too that these readers will turn their research efforts toward helping to develop feasible implementation strategies for the sort of approach that we recommend.

We hope to engage a third group of readers with this paper who are not previously acquainted with some of the price index bias problems that we focus on, including the sourcing substitution bias problems defined by Diewert and Nakamura (2010/2011) and for which Houseman et al. (2011) provide the first empirical results. We hope to provide these readers with a readily understandable exposition of these biases. We feel it is crucial for economists at large to understand how these inflation measurement distortions arise and why they have likely become more serious in recent years.

[10] Superlative indexes, defined by Diewert (1976, 1992) have many desirable properties when it comes to taking account of buyer substitution behavior but cannot properly account for the effects on the prices paid by buyers when that changes because buyers progressively learn about cheaper sources of products rather than because of suppliers lowering their prices. See also Diewert (1987, 2013a, 2013b), Diewert et al. (2002), Diewert and Nakamura (1993, 2007), and Nakamura (2013) regarding aspects of the Fisher index of relevance for the use of price indexes in the making of productivity indexes for nations.

2. Background Material

In this paper, we focus primarily on three main price indexes produced by the BLS: the Consumer Price Index (CPI), the Producer Price Index (PPI), and the Import Price Index (MPI). We seek to focus attention on one aspect of conventional official statistics price index making and abstract from many other important issues in the process. It should also be noted that although our discussion will focus on the handling of prices for physical products with associated UPCs, the major price indexes include services as well as goods categories.

Knowing some specifics of how price indexes are produced is helpful for considering price index bias problems. The official price indexes used to measure inflation first aggregate price relatives into elementary indexes for narrow categories of products, such as men's suits or crude petroleum. They then aggregate the elementary indexes, in most cases, employing a Laspeyres or similar formula.[11] Price relatives are ratios of current to previous period prices for specific products sold by specific establishments. The aggregation formula for an elementary price index typically includes weights for the price relatives that reflect shares of the total value of the transactions (and may also take sample selection probabilities into account). Similarly, weights that reflect shares of total expenditure comprised by the products covered by each of the elementary indexes are used to aggregate the elementary indexes to arrive at higher-level and overall inflation measures like the All Items CPI or the PPI for Final Demand.

The CPI is intended to measure the inflation experience of households, so the value share weights used for the CPI are based on household survey information. However, the product units included in the CPI basket are priced at selected retail outlets because it is operationally easier to collect prices from businesses.

The PPI primarily measures changes in prices received by domestic businesses in selling their products to other domestic or foreign businesses. Selected products are regularly priced at selected establishments of domestic producers. The PPI value share weights are based on what domestic businesses report as their sales revenues by product.

The BLS produces the MPI as part of its International Prices Program. The MPI is intended to be a measure of the inflation experience of domestic purchasers of imported products.

[11] The Laspeyres formula is defined below. It can be calculated in multiple stages of aggregation or in a single step. The Paasche index, also defined below, shares this convenient property.

Products are priced at selected U.S. importer establishments, and the value share weights are based on U.S. survey and customs data for all imports.

We find it useful to differentiate what we call primary product and auxiliary product attributes. We define *primary product attributes* (or simply *primary attributes*) as characteristics a product unit has when first sold by the original producer and that continue to be characteristics of the product unit regardless of where and how it may be resold on its way to the final purchaser. We define *auxiliary product unit attributes* (referred to sometimes simply as *auxiliary attributes*) as attributes that a product unit acquires as a consequence of where and how it is sold. For example, being sold during a promotional sale is a potentially relevant auxiliary attribute of a product unit in the studies of price evolution and consumer behavior. As Hausman and Leibtag (2007, 2010) note, most product markets offer a selection of differentiated product items to consumers, and this differentiation can include the different amenities provided by the different retail outlets where consumers shop. It is useful to differentiate these sorts of product unit attributes from the primary (or physical) product attributes that come from the good's producer and stay with it wherever it is sold.

3. Basic, Hybrid, and Conventional Versions of Laspeyres, Paasche, and Fisher Price Indexes

We begin this section with basic formulas for the Laspeyres, Paasche, and Fisher price indexes. These are the usual definitions given in economics and accounting textbooks and in the relevant scholarly literature, although it is important to note that the U.S. CPI relies on a weighted geometric mean formula to compute elementary indexes for physical commodities. We next take up the case of multiple transactions per product. The price indexes we develop for the multiple transactions case are what we recommend be used: that is, these are what we subsequently specify to be the target indexes.

We next show how our indexes for the multiple transactions case can be modified to allow for grouping the transactions each period. We then use our grouped transactions price index formulas to relate what we label as conventional formulas, which embody a key feature of current statistical agency practice, to our target indexes. Once we can explicitly relate the conventional to our target indexes, we show that formulas for the bias of the conventional indexes are easily derived.

3.1 Basic Versus Hybrid Price Indexes

We denote by $n = 1, \ldots, N$ the products in the domain of definition for a price index. The time period is denoted by t. All the price indexes considered involve two time periods (e.g., two months for a monthly index) denoted as t=0 and t=1 Each of the J_n^t transactions for product n in period t ($j = 1, \ldots, J_n^t$) involves a seller k and a purchaser k′. Hence, for transaction j in time period t for product n, $q_{n,k,k'}^{t,j}$ is the quantity of the product bought by purchaser k′ from seller k. This quantity is given in terms of the same units of measure used in reporting the price per unit of the product, and that price is denoted by $p_{n,k,k'}^{t,j}$.

In each segment of the paper, we simplify this notation to show just the superscripts and subscripts needed there. Hence, in the rest of this section, just the superscript t and the subscript n are used. The total nominal revenue received or remittance paid for product n in period t ($t = 0,1$) is thus denoted here by R_n^t, and the total received or paid for all N products is

(1) $$R^t = \sum_{n=1}^N R_n^t = \sum_{n=1}^N p_n^t q_n^t .$$

The basic Laspeyres price index (P_L) is given by[12]

(2) $$P_L^{0,1} = \frac{\sum_{n=1}^N p_n^1 q_n^0}{\sum_{n=1}^N p_n^0 q_n^0} = \frac{\sum_{n=1}^N \left(\frac{p_n^1}{p_n^0} \right) p_n^0 q_n^0}{\sum_{n=1}^N p_n^0 q_n^0} = \sum_{n=1}^N S_n^0 \left(\frac{p_n^1}{p_n^0} \right) ;$$

the basic Paasche index (P_P) is given equivalently by

(3) $$P_P^{0,1} = \frac{\sum_{n=1}^N p_n^1 q_n^1}{\sum_{n=1}^N p_n^0 q_n^1} = \left[\sum_{n=1}^N S_n^1 \left(\frac{p_n^1}{p_n^0} \right)^{-1} \right]^{-1} ;$$

[12] See, for example, UNECE et al. (2009, Chapter 10, p. 147, expression 10.1). There the quantity weights are for a base period other than the base period for the price observations because of the additional time often needed to obtain the data for estimating the index weights. We ignore this additional complication in this paper.

and the basic Fisher price index (P_F) is

(4) $$P_F^{0,1} = (P_L^{0,1} P_P^{0,1})^{1/2},$$

where S_n^t in (2) and in (3) denotes the value share of R^t for product n in period t given by

(5) $$S_n^t = \frac{p_n^t q_n^t}{\sum_{n=1}^{N} p_n^t q_n^t} = \frac{R_n^t}{R^t}.$$

From the final expression in (2) and also in (3), and from (4), we see that the basic Laspeyres, Paasche and Fisher price indexes are all summary metrics for price relatives given for product n ($n = 1, \ldots, N$) by

(6) $$p_n^1 / p_n^0.$$

To evaluate a basic price index formula such as (2) or (3), each specified product covered by the index can only have one price in each time period. Historically, competitive forces have been appealed to as a justification for this one price per product approximation to reality. Yet many businesses no longer set their prices on a product-by-product basis (if, indeed, most ever did that). Rather they use pricing strategies aimed at maximizing their overall rate of return on their product sales in which products are offered for sale at differing prices within a given market area and even sometimes by a single supplier.[13] Kaplan and Menzio (2014) use a large data set of prices for retail store transactions and show that the coefficient of variation of the average UPC price is 19 percent. The rapid rise of online retail promises even greater opportunities for complex pricing strategies (Tran, 2014).

3.2 Allowing for Multiple Transactions per Product at Multiple Prices

Suppose there are multiple transactions per product each period and that a product can sell for different prices in these transactions. Suppose, too, that we have the price and quantity details for the transactions. For these data to be used for price index evaluation, either we need a way of choosing one representative price per product for each product (the conventional

[13] There are many documented examples of narrowly defined products for both households and businesses being available from different producers for different prices. See, for example, Foster, Haltiwanger, and Syverson (2008), Byrne, Kovak, and Michaels (2009) and Klier and Rubenstein (2009).

approach), or the raw data *must* be represented using some sort of price and quantity summary statistics. We use the word “must” because, in general, the number of transactions will not be the same from one time period to the next. Hence, the transactions data must be summarized in some way to have paired observations on the price in the two time periods covered by the index that can be used to form price relatives. Generating price observations that can be compared over time is a necessary step in constructing price indexes using scanner or other raw transactions data.

The existence of multiple prices for a product in a time period can cause two kinds of bias in a price index. The “formula bias” problem arises if a single price is selected to represent the multiple prices that exist in a given time period, and the formula for the elementary price index is an arithmetic average of price relatives calculated as the ratio of the selected price for period 1 to the selected price for period 0. When multiple prices are present in the population and a single price is selected to represent the population in the price index, the price that is used in the price index becomes a random variable. Assuming that the two random variables are not perfectly correlated, the expected value of a ratio of random variables is an increasing function of the variance of the denominator, so the greater the variance of the price observations, the greater the upward bias in the average of price relatives. In the CPI of the U.S. and many other countries, formula bias is avoided by using geometric means to form the elementary indexes. The geometric mean of a set of price relatives is the same as the ratio of geometric means of the prices, so a geometric mean elementary index is, in effect, a ratio of average prices. The variance of the denominator will be so small that formula bias is not a problem if many price observations are averaged and the index is calculated as a ratio of the average prices.

The second kind of bias that can occur if a single price is used to represent the multiple prices that are present in a time period is that the behavior of the selected price may be unrepresentative of what is going on with the distribution of prices that are available to buyers. It is this problem that the rest of this paper will focus on. Nevertheless, it should be noted here that the unit value approach that we will recommend for reasons of maintaining sample representativeness also has benefits for eliminating formula bias and improving the statistical properties of the index. (For additional background on formula bias, see Reinsdorf, 1999a; McClelland and Reinsdorf, 1999; and Reinsdorf and Triplett, 2009.)

We denote the yet-to-be specified price and quantity summary statistics for each product n in each period t by $p_n^{t,S}$ and $q_n^{t,S}$. The nominal value of the j[th] transaction is $R_n^{t,j} = p_n^{t,j} q_n^{t,j}$. Thus the nominal value of all transactions for product n in period t is

$$(7) \qquad R_n^t = \sum_{j=1}^{J_n^t} R_n^{t,j} = \sum_{j=1}^{J_n^t} p_n^{t,j} q_n^{t,j} .$$

If the important auxiliary product unit attributes do not vary across transactions, the following condition should hold for each of the N products covered by the price index:

$$(8) \qquad \frac{R_n^1}{R_n^0} = \left(\frac{p_n^{1,S}}{p_n^{0,S}}\right)\left(\frac{q_n^{1,S}}{q_n^{0,S}}\right).$$

This condition says that the growth in the per period value of all transactions for product n from period 0 to 1 can be expressed as the product of a pure price change ratio times a pure quantity change ratio. We call this condition the *product level product rule*.[14]

The product level product rule will always hold if for each period ($t = 0,1$) the product of the price and quantity summary statistics equals the nominal value figure:

$$(9) \qquad R_n^t = p_n^{t,S} q_n^{t,S} .$$

Moreover, it is readily apparent that condition (9) will always hold if the quantity and price summary statistics are defined for each period ($t = 0,1$) as

$$(10) \qquad q_n^{t,S} = \sum_{j=1}^{J_n^t} q_n^{t,j} = q_n^t \quad \text{and}$$

$$(11) \qquad p_n^{t,S} = R_n^t / q_n^{t,\bullet} = \overline{p_n^{t,\bullet}} ,$$

where the dot ($\bullet$) replaces the index over which the summation is taken to compute the per unit price average.[15] The price summary statistic given in (11) is the period t *unit value* for product n.

[14] While not defining the product level product rule that we do here, von der Lippe and Diewert (2010) do make a similar sort of argument. They note that economic agents often purchase and sell the same commodity at different prices over a single accounting period. They assert that a bilateral index number formula requires that these multiple transactions in a single commodity be summarized in terms of a single price and quantity for the period. They explain moreover that if the quantity is taken to be the total number of units purchased or sold during the period and it is desired to have the product of the price summary statistic and the total quantity transacted equal to the value of the transactions during the period, then the single price must be the average value. They note that this point was also made by Walsh (1901, p. 96; 1921, p. 88) and Davies (1924, 1932) and more recently by Diewert (1995/2012). See Diewert (1987) and Diewert and Nakamura (2007) on the conventional product test.

The quantity summary statistic given in (10) is the total quantity transacted of product n in the given period t.

Substituting the period t unit value, $\overline{p_n^{t,\bullet}}$, for the price variable p_n^t in the basic specifications for the Laspeyres and Paasche indexes given in (2) and (3), and redefining the quantity variable as the summation over all transactions in the given period, we obtain, respectively, the following expressions for what we call the *hybrid Laspeyres index* (the *HLaspeyres index* for short)[16]

$$(12) \qquad P_{HL}^{0,1} = \frac{\sum_{n=1}^{N} \overline{p_n^{1,\bullet}} q_n^0}{\sum_{n=1}^{N} \overline{p_n^{0,\bullet}} \; q_n^0} = \frac{\sum_{n=1}^{N} \left(\dfrac{\overline{p_n^{1,\bullet}}}{\overline{p_n^{0,\bullet}}} \right) \overline{p_n^{0,\bullet}} q_n^0}{\sum_{n=1}^{N} \overline{p_n^{0,\bullet}} \; q_n^0} = \sum_{n=1}^{N} S_n^0 \left(\frac{\overline{p_n^{1,\bullet}}}{\overline{p_n^{0,\bullet}}} \right)$$

and for the *hybrid Paasche index* (the *HPaasche index*):

$$(13) \qquad P_{HP}^{0,1} = \frac{\sum_{n=1}^{N} \overline{p_n^{1,\bullet}} q_n^1}{\sum_{n=1}^{N} \overline{p_n^{0,\bullet}} q_n^1} = \left[\sum_{n=1}^{N} S_n^1 \left(\frac{\overline{p_n^{1,\bullet}}}{\overline{p_n^{0,\bullet}}} \right)^{-1} \right]^{-1} .$$

Thus, the *hybrid Fisher index* (the *HFisher index*) is given by

$$(14) \qquad P_{HF}^{0,1} = (P_{AL}^{0,1} P_{AP}^{0,1})^{1/2} .$$

The value share weights in (12) and (13), S_n^0 and S_n^1, are given for all n by

$$(15) \qquad S_n^t = R_n^t / R^t ,$$

with R_n^t now given by (7) and where $R^t = \sum_{n=1}^{N} R_n^t$.

The HLaspeyres, HPaasche, and HFisher indexes use unit values for the first stage of aggregation, so they can explicitly accommodate a product being transacted at multiple prices within a unit time period. They reduce to the basic formulas in situations in which there truly is

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[15] Note that if there truly is just one price for each unit time period as each product n is defined, then each individual price observation equals $\overline{p_n^{t,\bullet}}$ for the given n,t combination. Hence, condition (11) will be satisfied when the conventional statistical agency practice of utilizing a single price observation for each product in each time period is followed.

[16] The term "hybrid" was suggested to Marshall Reinsdorf by Harlan Lopez of the Central Bank of Nicaragua.

just one price per period for each product. From (12)-(14), we see too that the HLaspeyres, HPaasche, and HFisher indexes are summary metrics for relatives of average prices (i.e., what we will refer to as *unit value price relatives*) defined as:

$$(16) \qquad (\overline{p_n^{1,\bullet}} / \overline{p_n^{0,\bullet}}) .$$

These unit value price relatives reduce to the usual price relatives given in (6) when there is just one price per period for each product. Thus, the HLaspeyres, HPaasche, and HFisher formulas are generalizations of the basic formulas.

Analysts who have estimated price indexes using raw scanner or other transactions level data[17] from merchants or from financial markets are, in fact, already accustomed to evaluating price indexes based on unit value price relatives,[18] but they have not always made this practice explicit by spelling out the data processing specifics. By calling attention to how formulas (12)-(16) depart from the corresponding basic formulas, and by providing terminology for these practices, we hope to facilitate efforts aimed at finding practical solutions to the problems statistical agencies face when dealing with the reality of multiple prices per product per period.

3.3 An Important Historical Clarification

We chose to label as "Hybrid" indexes the Laspeyres, Paasche, and Fisher formulas given in (12)-(14) above. But, in fact, these are the "true" Laspeyres, Paasche, and Fisher indexes as introduced by the original authors. Only one of the multiple authors of this paper (namely, W. Erwin Diewert) had the language skills needed to go back to the original German articles by Laspeyres (1871) and Paasche (1874). However, Walsh (1901, 1921) and Fisher (1922) wrote in English and are quite explicit that unit value prices and total quantities transacted in the given time period and market place are the "right" p's and q's that should be used in a bilateral index number formula at the first stage of aggregation over transactions that take place at different prices within the period.

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[17] By "raw," we mean transactions data not already aggregated over time. Providers of what is labeled as "transactions data" often, in fact, deliver data sets consisting of the total quantities transacted and the unit values for some unit time period such as a week. See, for instance, Nakamura, Nakamura, and Nakamura (2011) for a study done using transactions data of this sort.

[18] See, for example, Ivancic, Diewert, and Fox (2011) and Nakamura, Nakamura, and Nakamura (2011).

Of course, when authors put their creations into the public domain, they cannot control how others alter what they originally proposed. It is clear that large numbers of authors have defined and used the indexes as in (2)-(4) above, which are what we have labeled as the "Basic" indexes. And official statistics agencies have typically defined and used the indexes in the form we give subsequently (in (31)-(33)), which we have labeled the "Conventional" indexes. It is in this context, and in the context of the uses we make of the indexes subsequently in this paper, that we refer to formulas (12)-(14) as "Hybrid" indexes.

3.4 Working with Grouped Transactions Data

Suppose we want to divide the transactions for the N products covered by a price index according to one or more auxiliary attributes. For transaction j for product n in period t, the price and quantity are denoted here by $p_n^{t,j}$ and $q_n^{t,j}$. We can designate a total of C exhaustive and mutually exclusive groups for the transactions: $G1,\ldots,GC$. For each group of transactions, the total quantity and the average price (i.e., the group quantity and the group unit value) are given, respectively, by

(17) $$q_n^{t,Gc} = \sum_{j\in Gc} q_n^{t,j} \quad \text{and} \quad p_n^{t,Gc} = (\sum_{j\in Gc} p_n^{t,j} q_n^{t,j}) / q_n^{t,Gc}.$$

Hence for each product n, the overall quantity transacted in period t can be represented as:

(18) $$q_n^t = q_n^{t,G1} + \ldots + q_n^{t,GC} = \sum_{Gc=G1}^{GC} \left(\sum_{j\in Gc} q_n^{t,j} \right).$$

The overall unit price for product n in period t can now be given as

(19) $$\overline{p_n^{t,\bullet}} = (\sum_{Gc=G1}^{GC} \sum_{j\in GC} p_n^{t,j} q_n^{t,j}) / q_n^t = (\sum_{Gc=G1}^{GC} p_n^{t,Gc} q_n^{t,Gc}) / q_n^t = \sum_{Gc=G1}^{GC} p_n^{t,Gc} s_n^{t,Gc},$$

where for group $Gc = G1,\ldots,GC$, we have the following for the quantity shares, $s_n^{t,Gc}$, for groups $Gc = 1,\ldots,GC$ we have

(20) $$s_n^{t,Gc} = q_n^{t,Gc} / q_n^t \quad \text{with} \quad s_n^{t,G1} + \ldots + s_n^{t,GC} = 1.$$

Note that the quantity shares defined in (20) can only be meaningfully computed when the product units being added are *homogeneous with respect to their primary attributes*. With this proviso, when the total quantity transacted in period t is computed as in (18) and the period t unit value for each product n is computed as in (19), then the HLaspeyres, HPaasche, and HFisher formulas given in (12)-(14) can be evaluated. In other words, the only adjustment needed in this grouped transactions case is to use (18) and (19), rather than (10) and (11), to compute the quantity and price summary statistics.

3.5 A Formula for the Bias in Conventional Laspeyres, Paasche, and Fisher Indexes

As noted, with some exceptions, the conventional statistical agency practice is to collect just *one* price to represent a product in an establishment in a time period. Without loss of generality, we denote the one transaction used in the conventional index as transaction 1 (i.e., as $j = 1$). The full set of transactions in a given period t for each product n can then be divided into two mutually exclusive and exhaustive groups, G1 and G2, with G1 containing the single transaction used in compiling a conventional price index and G2 containing the rest of the transactions, which are transactions ignored in the conventional way of compiling the index. Hence for G1, the quantity and price summary statistics can be denoted, respectively, as

(21) $q_n^{t,G1} = q_n^{t,1}$ and $p_n^{t,G1} = p_n^{t,1}$,

and, from (17), we see that for group G2 we have

(22) $q_n^{t,G2} = \sum_{j=2}^{J_n^t} q_n^{t,j} = \sum_{j \in G2} q_n^{t,G2}$ and $p_n^{t,G2} = (\sum_{j=2}^{J_n^t} p_n^{t,j} q_n^{t,j}) / q_n^{t,G2} = (\sum_{j \in G2} p_n^{t,j} q_n^{t,j}) / q_n^{t,G2}$,

where $q_n^{t,G2}$ is the quantity total and $p_n^{t,G2}$ is the unit value for the G2 transactions.

The total quantity transacted for each product n in period t is the sum of the transactions quantities for the G1 and the G2 groups, so we have

(23) $q_n^t = \sum_{j=1}^{J_n^t} q_n^{t,j} = \sum_{j \in G1} q_n^{t,j} + \sum_{j \in G2} q_n^{t,j} = q_n^{t,G1} + q_n^{t,G2}$.

And, from the last expression in (19), the overall unit price for product n in period t is

(24) $\overline{p_n^{t,\bullet}} = p_n^{t,G1} s_n^{t,G1} + p_n^{t,G2} s_n^{t,G2}$,

where now for the quantity share statistics we have:

(25) $s_n^{t,G1} = q_n^{t,G1}/q_n^t$ and $s_n^{t,G2} = q_n^{t,G2}/q_n^t$ with $s_n^{t,G1} + s_n^{t,G2} = 1$.

For our price index bias analyses in Section 4, it will prove useful to define a factor relating the average of the G2 transaction prices to the single G1 price. The *product specific discount factor*, d_n^t, is defined such that one minus this discount factor is the factor of proportionality relating the average for the ignored G2 prices to the G1 price:

(26) $p_n^{t,G2} = (1 - d_n^t)p_n^{t,G1}$.

When the average price for the G2 transactions for product n in period t is less than the corresponding G1 price, then d_n^t will be strictly between 0 and 1. When the average for the G2 prices is greater than the G1 price, then d_n^t will be negative, making $(1 - d_n^t)$ greater than 1.

The overall average price can now be represented as follows for product n in period t:

$$
\begin{aligned}
\overline{p_n^{t,\bullet}} &= (p_n^{t,G1}s_n^{t,G1} + p_n^{t,G2}s_n^{t,G2}) && \text{using (24)} \\
&= p_n^{t,G1}s_n^{t,G1} + (1 - d_n^t)p_n^{t,G1}s_n^{t,G2} && \text{using (26)} \\
&= p_n^{t,G1}s_n^{t,G1} + p_n^{t,G1}s_n^{t,G2} - d_n^t p_n^{t,G1}s_n^{t,G2} && \\
&= p_n^{t,G1}(s_n^{t,G1} + s_n^{t,G2}) - d_n^t p_n^{t,G1}s_n^{t,G2} && \text{where } s_n^{t,G1} + s_n^{t,G2} = 1 \\
&= (1 - d_n^t s_n^{t,G2})p_n^{t,G1} && \text{after factoring out } p_n^{t,G1}.
\end{aligned} \tag{27}
$$

We see from the last line of (27) that what we label as the *price quote representativeness term*, given by $(1 - d_n^t s_n^{t,G2})$, relates the unit value for *all* the period t transactions for product n to the one price quote used when following conventional index-making practice.

Now define a product-specific price index representativeness factor $\gamma_n^{0,1}$ as the ratio of the price quote representativeness terms for period 1 versus period 0:

(28) $\gamma_n^{0,1} = \dfrac{1 - d_n^1 s_n^{1,G2}}{1 - d_n^0 s_n^{0,G2}}$.

This *price index representativeness factor* equals 1 when the representativeness term has the same value in both period 0 and period 1. So long as this factor is approximately equal to 1, then the overall average price for product n is related in the same manner in both periods 0 and 1 to the one price quote conventionally utilized each period. In contrast, values of $\gamma_n^{0,1}$ that are appreciably different from 1 indicate that there is a difference between periods 0 and 1 in how the overall average price relates to the price quote utilized. (Note that $\gamma_n^{0,1}$ exists and is positive if there are at least two transactions per period; $s_n^{t,G2}$ must be strictly less than 1 because G1 must contain a transaction for some positive quantity in both time periods and d_n^t must be strictly less than 1 since the average G2 price is positive in either time period.)

The last expression for the HLaspeyres price index given in (12) can now be restated to incorporate the *relative price index representativeness factor* $\gamma_n^{0,1}$:

$$P_{HL}^{0,1} = \sum_{n=1}^{N} S_n^0 \left(\frac{\overline{p_n^{1,\bullet}}}{\overline{p_n^{0,\bullet}}} \right) = \sum_{n=1}^{N} S_n^0 \left[\frac{(1-d_n^1 s_n^{1,G2}) p_n^{1,G1}}{(1-d_n^0 s_n^{0,G2}) p_n^{0,G1}} \right] \qquad \text{using (27)}$$

(29)
$$= \sum_{n=1}^{N} S_n^0 \left[\frac{\left(\frac{1-d_n^1 s_n^{1,G2}}{1-d_n^0 s_n^{0,G2}} \right) p_n^{1,G1}}{p_n^{0,G1}} \right]$$

$$= \sum_{n=1}^{N} S_n^0 \left(\gamma_n^{0,1} \times \frac{p_n^{1,G1}}{p_n^{0,G1}} \right) \qquad \text{using (28).}$$

Similarly, the HPaasche price index given in (13) can be restated as

(30)
$$P_{HP}^{0,1} = \left[\sum_{n=1}^{N} S_n^1 \left(\gamma_n^{0,1} \times \frac{p_n^{1,G1}}{p_n^{0,G1}} \right)^{-1} \right]^{-1}.$$

The HFisher counterpart of (29) and (30) is still given by (14), but with the HLaspeyres and HPaasche components now given by (29) and (30).

We are now ready to define the price index formulas we will refer to as conventional.[19] To obtain the *conventional Laspeyres price index* ($P_{CL}^{0,1}$), we substitute $(p_n^{1,G1}/p_n^{0,G1})$ for $(\overline{p_n^{1,\bullet}}/\overline{p_n^{0,\bullet}})$ in the first expression for $P_{HL}^{0,1}$ given in (29), in accord with the conventional practice of only using one price observation per product in each time period:

[19] In defining these formulas, we ignore the important aspect of conventional practice that is the focus of the Lowe index literature: namely, that the data used in estimating the value shares is collected separately from the price information used in index making, and is not usually even for the same time periods. See Diewert (1993) and Balk (2008, chapter 1) for more on this issue.

(31) $$P_{CL}^{0,1} = \sum_{n=1}^{N} S_n^0 \left(\frac{p_n^{1,G1}}{p_n^{0,G1}} \right).$$

Similarly, to obtain *the conventional Paasche price index* ($P_{CP}^{0,1}$), we substitute $(p_n^{1,G1}/p_n^{0,G1})$ for $(\overline{p_n^{1,\bullet}}/\overline{p_n^{0,\bullet}})$ in the first expression for $P_{HP}^{0,1}$ given in (30), again in accord with the conventional practice of only using one price observation per product in each time period:

(32) $$P_{CP}^{0,1} = \left[\sum_{n=1}^{N} S_n^1 \left(\frac{p_n^{1,G1}}{p_n^{0,G1}} \right)^{-1} \right]^{-1}.$$

The conventional Fisher price index ($P_{CF}^{0,1}$) is given by:

(33) $$P_{CF}^{0,1} = (P_{CL}^{0,1} P_{CP}^{0,1})^{1/2}.$$

In the index number literature, the term "bias" refers to a systematic difference between the result that would be obtained for some index in use or considered for use versus a specified target index. To this point, we have only demonstrated the price index representativeness factor as an outcome of sampling error: Basing an index on one product item will yield a different answer from using the entire population of product prices. In Section 4 below, however, we present reasons why the price of the selected item could have a systematically different expectation from the population unit value. If we use P_{AL} given in (29) as the target index, then the bias of the conventional Laspeyres index given in (31) is:

(34) $$\begin{aligned} B_{CL}^{0,1} &= P_{CL} - P_{HL} \\ &= \sum_{n=1}^{N} S_n^0 \left(\frac{p_n^{1,G1}}{p_n^{0,G1}} \right) - \sum_{n=1}^{N} S_n^0 \left[\gamma_n^{0,1} \frac{p_n^{1,G1}}{p_n^{0,G1}} \right] \\ &= \sum_{n=1}^{N} (1 - \gamma_n^{0,1}) S_n^0 \left(\frac{p_n^{1,G1}}{p_n^{0,G1}} \right) \\ &= \sum_{n=1}^{N} \left(\frac{d_n^1 s_n^{1,G2} - d_n^0 s_n^{0,G2}}{1 - d_n^0 s_n^{0,G2}} \right) S_n^0 \left(\frac{p_n^{1,G1}}{p_n^{0,G1}} \right) \qquad \text{using (28).} \end{aligned}$$

Similarly, using (32) and (30) for the conventional Paasche index, the bias is:

$$B_{CP}^{0,1} = P_{CP} - P_{HP}$$

(35)
$$= \sum_{n=1}^{N}\left[S_n^1\left(\frac{p_n^{1,G1}}{p_n^{0,G1}}\right)^{-1}\right]^{-1} - \sum_{n=1}^{N}\left[S_n^1\left(\gamma_n^{0,1}\frac{p_n^{1,G1}}{p_n^{0,G1}}\right)^{-1}\right]^{-1}$$

It is cumbersome to develop a bias formula for the conventional Fisher index given in (33). However, as Diewert and Nakamura (2010/2011, Appendix) explain, it is straightforward to develop formulas for the differences between the arithmetic averages of the Laspeyres and Paasche components for the conventional and for the target Laspeyres and Paasche components, respectively, of the conventional and the target Fisher indexes.[20] Thus, the bias of the conventional Fisher index can be approximated by

(36) $$B_{CF}^{0,1} = P_{CF}^{0,1} - P_{HF}^{0,1} \cong [(P_{CL}^{0,1} + P_{CP}^{0,1})/2] - [(P_{HL}^{0,1} + P_{HP}^{0,1})/2].$$

4. Different Sorts of Price Index Selection Bias

In the following section, we show how expression (34) can be used to represent and provide a framework of analysis for multiple sorts of price index bias. We focus here on the Laspeyres bias formula because the BLS and other statistical agencies mostly use the Laspeyres index in their inflation measurement programs. However, comparable results for the Paasche and Fisher formulas can be derived starting instead from (35) or (36).

4.1 Outlet Substitution Bias in the CPI

For the CPI, the BLS collects prices from selected retail outlets. In an effort to control for possible price determining factors that can differ even for the same commercial product (i.e., to control for what we call auxiliary product unit attributes), the BLS only forms price relatives for product units sold at the same retail outlet (see Greenlees and McClelland, 2011). Suppose, however, that households mostly care about what they must pay for products characterized by their primary attributes (including the brand and producer), and hence shift their expenditures among retail outlets in response to advertising about pricing policies and temporary promotional sales. The benefits of this sort of price-informed shopping in terms of the prices actually paid for

[20] For more, see Diewert and Nakamura (2010/2011, Appendix).

the products used by any one consumer will be missed by a practice of only pairing prices for the same retail outlet in forming price relatives. If the ratio of the average price paid to the price used in the index is falling because opportunities for paying discounted prices are increasing, the conventional index will be upward biased.

The potential for outlet-specific price relative evaluation to cause CPI price index bias was noted decades ago. In a 1962 report, Edward Denison raised the concern that, in his words, "revolutionary changes in establishment type that have taken place in retail trade" may have caused "a substantial upward bias" in the CPI (p. 162).[21]

Marshall Reinsdorf empirically investigated Denison's CPI bias hypothesis. The BLS produces average price (AP) series for selected food groups. These are unit value series for certain food categories, though not for strictly homogeneous products as we advocate. Reinsdorf (1993) compared selected AP series for food and gasoline with the corresponding CPI component series. He discovered that from 1980 to 1990, the CPI and AP series for comparable products diverged by roughly 2 percentage points a year, with the CPI series rising *faster* than the AP series, as would be expected if the CPI systematically fails to capture the benefits to consumers of price-motivated retail outlet switching. These empirical results captured the attention of W. Erwin Diewert, inspiring him to derive a formula for what he called the outlet substitution bias problem (Diewert, 1998).

Reinsdorf (1999a) later found that formula bias in the CPI caused part of the divergences between CPIs and corresponding AP series, so the outlet substitution effects turned out to be 0.25 percent per year for both food and gasoline. The combined efforts of Reinsdorf and Diewert then galvanized other economists and price statisticians to take the outlet substitution bias problem seriously.[22]

If a significant number of consumers regularly switch where they shop among multiple retail outlets depending on the product prices each is currently offering, then we would expect d_n^t defined in (26) to be strictly between 0 and 1 in value for both periods 0 and 1. This alone,

[21] For more on the practical aspects of these "revolutionary changes" that Denison (1962) noted and foresaw, see Brown (1997), Garg et al. (1999), Freeman et al. (2011), Hausman and Leibtag (2007, 2010), and Senker (1990).

[22] Important papers on this topic include Moulton (1993, 1996a, 1996b), Hausman (2003), Hausman and Leibtag (2007, 2010), and Greenlees and McClelland (2011). Also, White (2000) presents related evidence for Canada.

however, will not cause a bias problem. We see from (34) that the key question is whether the term $d_n^t s_n^{t,G2}$ has been *changing* in value over time. If the value of this term happened to stabilize, then there would be no outlet substitution bias. We believe, however, that the G2 quantity share ($s_n^{t,G2}$) has been growing over time for two complementary reasons. The first is that modern information technologies have made it cheaper and easier for retailers to hold temporary promotional sales, which tend to generate high demand. The second is that there have been steady improvements in consumer access to current information about retail prices at different outlets in their market areas including now even smartphone geotargeted advertising. Hence, we expect the Laspeyres index bias given by (34) to be positive.

4.2 CPI Promotional Sale Bias

Outlet substitution bias discussed previously can result from a failure to capture a growing trend for consumers to take advantage of temporary sale and other price differences *among* retail outlets. However, even at the *same* retail outlet, units of a product are often sold at both regular and promotional sale prices within a month, which is the unit time period for the CPI. The frequency of temporary sales is believed to have been increasing in the U.S. The information available to consumers about sale pricing has been steadily expanding too, presumably allowing consumers to take progressively greater advantage of temporary promotional sale prices.[23]

The BLS collects and uses for the CPI whatever prices are in effect at the time the price quotes are collected from each selected retail outlet, regardless of whether the prices are identified as "sale" or "regular" prices.[24] Temporary sales are believed to be in effect for any one product at any one outlet for less than half of the days or hours of business. Hence, the value of d_n^t is expected to be predominantly between 0 and 1. Nevertheless, because the capture of regular or sale prices is random, the value of can be either positive or negative.

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[23] For more on the importance of temporary sales for explaining retail price dynamics, see Pashigian (1988), Pesendorfer (2002), and Nakamura and Steinsson (2008, 2012).

[24] The same is true for Statistics Canada (1996, p. 5): "Since the Consumer Price Index is designed to measure price changes experienced by Canadian consumers, the prices used in the CPI are those that any consumer would have to pay on the day of the survey. This means that if an item is on sale, the sale price is collected." The BLS does, however, have other special procedures for handling sale prices of apparel at the end of the selling season.

The volumes sold at promotional sale prices tend to be large, and, as already stated, the frequency of temporary sales is believed to have been rising in the U.S. at least. As is evident from equation (28), the sign of the change in the term $d_n^t s_n^{t,G2}$ determines the sign of promotions bias.[25] Because the U.S. CPI includes sales prices in proportion to the percent of time in which they are offered, increased frequency of sales could result in either a rise or a fall in this term. A fall would occur if the increased frequency of sale price offerings increased the relative frequency of sale prices being selected for the CPI by more than it increased the relative frequency of sale prices being paid by consumers. On the other hand, if consumers' costs of acquiring information fall, the term would likely rise, implying positive promotions bias. Information costs have, indeed, fallen, so promotions bias may be positive on average.[26]

4.3 Sourcing Substitution Biases in the PPI and MPI

Finding cheaper input sources and then making sourcing substitutions is a prevalent strategy for lowering business costs. Empirical evidence suggests that this sort of supplier switching behavior plays an economically important role in the survival and growth of new firms (e.g., Foster, Haltiwanger, and Syverson, 2008; Bergin, Feenstra and Hanson, 2009).[27] If both the old and the new suppliers are domestic, it is the uses of the PPI as a deflator for inputs that can be affected. If both the old and the new suppliers are foreign, the MPI can be affected.

For both the PPI and MPI cases, we would expect the values of d_n^t in (26) to be strictly between 0 and 1. Moreover, we would expect the G2 quantity share ($s_n^{t,G2}$) to have been growing over time due to expanding information availability about suppliers and their prices,

[25] The statistical agencies for some U.S. trading partners such as Japan exclude temporary sale prices in compiling their Consumer Price Indexes (CPIs). For example, price collectors are instructed by the Statistics Bureau of Japan not to collect sale prices. More specifically, price collectors are instructed that "the following prices are excluded: Extra-low prices due to the bargain sales, clearance sales, discount sales, etc., which are held for less than seven days," Statistics Bureau of Japan (2012, p. 3, item 10). See also Imai, Shimizu and Watanabe (2012). This methodology difference could definitely affect international comparisons of inflation, economic growth, and well-being, and formula (34) can be useful for understanding these effects.

[26] We thank Brent Moulton for comments that greatly improved this section of the paper.

[27] Supply chain models like what Oberfield (2013) specifies assume that much of what typically is measured as technical progress in fact reflects the cost savings from supplier switches.

enabling purchasers to take greater advantage of lower price offers. Hence, we would expect positive biases in the relevant price indexes from sourcing substitutions.[28]

We next provide a simple example illustrating this bias problem for the MPI. Then, we go on to take up two other possible sorts of producer sourcing changes that may cause bias problems.

4.4 An Example of MPI Sourcing Substitution Bias Due to Import Sourcing Switches

Here we distinguish a supplier (k) from a buyer (k'). For our example, businesses 1 and 2 are foreign suppliers (hence, $k = 1,2$) and businesses 3 and 4 are domestic buyers (hence, $k' = 3,4$) for a single product. The quantities and prices are denoted by $q^t_{k,k'}$ and $p^t_{k,k'}$. With only one product, a Laspeyres (or Paasche or Fisher) price index reduces simply to a ratio of a single price or average price for the one product in each of the two time periods for the price index.

Table 1. Value Flows for the Four Businesses

Output Flows		**Input Flows**	
Business 1	**Business 2**	**Business 3**	**Business 4**
	Period 0 Value Flows		
$p^0_{1,3}q^0_{1,3}$	$p^0_{2,4}q^0_{2,4}$	$-p^0_{1,3}q^0_{1,3}$	$-p^0_{2,4}q^0_{2,4}$
	Period 1 Value Flows		
$p^1_{1,3}q^1_{1,3}$	$p^1_{2,3}q^1_{2,3} + p^1_{2,4}q^1_{2,4}$	$-p^1_{1,3}q^1_{1,3} - p^1_{2,3}q^1_{2,3}$	$-p^1_{2,4}q^1_{2,4}$

The value flows summarized in Table 1 reflect the following specifics:

- Business 1 is a developed country supplier to business 3, with this supply arrangement having been in place already for more than two periods at the start of period 0 for this example.

[28] Houseman et al. (2011) provide a variety of relevant empirical evidence for the MPI case.

- Business 2 is a cheaper, developing country supplier that has a supply arrangement with business 4 that was in place already for more than two periods as of the start of period 0.
- Business 3 purchases from business 1 in both periods 0 and 1. In period 1, business 3 also enters into a new purchasing relationship with the low cost supplier 2. Houseman et al. (2011) note the potential importance of the entry of lower-cost suppliers in the domestic economy (as well as competition from foreign producers, which is the case to which they devote more attention). What a new supplier charges has no effect on the "conventional" price index.
- Business 4 has had an ongoing purchasing relationship with business 2 and continues to buy exclusively from business 2 in periods 0 and 1.
- The following inequalities hold: $p^0_{1,3} > p^0_{2,4} > 0$, $p^1_{1,3} > p^1_{2,4} > 0$, $p^1_{1,3} > p^1_{2,3} > 0$.

The price indexes for domestic businesses 3 and 4 can be regarded as MPI index series.

The conventional price index for business 4, $P^{(4)}_{CL}$, is the same as our hybrid Laspeyres target price index for that business, $P^{(4)}_{HL}$, because business 4 uses just one supplier each period. There is no bias problem for $P^{(4)}_{CL}$. For this case, the conventional price index equals the target price index:

(37) $$P^{(4)}_{CL} = p^1_{2,4} / p^0_{2,4} = P^{(4)}_{HL}.$$

In contrast, we can show that the conventional price index for business 3 is biased, and we can show what the bias depends on. For business 3, the conventional price index is:

(38) $$P^{(3)}_{CL} = p^1_{1,3} / p^0_{1,3} = 1 + i,$$

where $(1+i)$ is the measured inflation rate using this conventional price index. This conventional price index takes no account of the fact that in period 1, business 3 not only bought from business 1 but also used a new supplier, business 2. In contrast, and under our assumption that business 3 views the products from the two suppliers as equivalent, the specified target index for business 3 uses the information for all the transactions in period 1. This price information is summarized in period 1 by the unit value, $\overline{p^1_{\bullet,3}}$; i.e., we have

(39) $$\overline{p^1_{\bullet,3}} = \frac{p^1_{1,3}q^1_{1,3} + p^1_{2,3}q^1_{2,3}}{q^1_{1,3} + q^1_{2,3}} = p^1_{1,3}s^1_{1,3} + p^1_{2,3}s^1_{2,3},$$

where

(40) $$s^1_{1,3} = \frac{q^1_{1,3}}{(q^1_{1,3} + q^1_{2,3})},\ s^1_{2,3} = \frac{q^1_{2,3}}{(q^1_{1,3} + q^1_{2,3})},\ \text{and}\ s^1_{1,3} + s^1_{2,3} = 1.$$

Hence the target output price index for business 3 is given by

(41) $$P^{(3)}_{HL} = u^1_3 / p^0_{1,3} = (p^1_{1,3} / p^0_{1,3})s^1_{1,3} + (p^1_{2,3} / p^0_{1,3})s^1_{2,3}.$$

It is the price charged by the lower priced supplier, business 2, that is ignored by the conventional price index for business 3. The price charged by business 2 is what constitutes the G2 group price for this example, whereas $p^1_{1,3}$ is the G1 price. Using (26), we have

(42) $$p^1_{1,3} = (1 - d^1)p^1_{2,3},$$

where $0 < d^1 < 1$. In period 0, there is only the one supplier for business 3. Hence, applying (34) yields:[29]

(43) $$\begin{aligned} B^{0,1}_{CL} &= P^{(3)}_{CL} - P^{(3)}_{HL} \\ &= d^1 s^1_{2,3}\left(\frac{p^1_{1,3}}{p^0_{1,3}}\right) \\ &= d^1 s^1_{2,3}(1 + i) > 0 \qquad \text{using (38).} \end{aligned}$$

The last two lines of (43) are convenient alternative expressions for the sourcing substitution bias of $P^{(3)}_{CL}$.

We note that the last expression in (43) is the same as equation (12) in Diewert and Nakamura (2010/2011).[30] This bias is seen to depend on:

[29] Note that the terms in (34) involving d^0_n drop out of the final expression in this case, and here we have $S^0 = 1$ because, in period 0, there is only the one supplier for business 3 charging a single price.

[30] Equation (2) in Reinsdorf and Yuskavage (2014) modifies this formula to use a value share weight instead of a quantity share by multiplying by a factor that is between 1 and $1/d^1$. Also, Houseman et al. (2011, p. 70) derive a

- the rate of price inflation as measured by the conventional index;
- the proportional cost advantage of any ignored supply source(s); and
- the quantity share for any ignored supply source(s).

If estimates can be made for the above factors, then a rough approximation to the bias given in (43) can be made using this formula, which is a special case of our general bias formula (34).

4.5 Domestic to Foreign Supplier Switches and a Proposed True Input Price Index (IPI)

We next consider the case of a business that switches from using a domestic supplier to a foreign one, thereby benefiting from an input cost decrease.[31] Neither the PPI nor the MPI can capture the cost savings from this sort of a sourcing substitution. The PPI's domain of definition does not include imports, and the MPI measures price changes beginning in the second month in which a newly selected imported product is observed. The resulting price index coverage gap is worrisome since most of the increase in the relative importance of trade in the U.S. economy is accounted for by the expansion of imports of intermediate products.[32]

The pricing gap between the PPI and the MPI programs could be closed by creating a true IPI program that is defined to measure the inflation experience of producers in buying their inputs from all sources: foreign as well as domestic. In this case, the price evolutions measured should include those associated with shifts in purchase shares from more to less expensive domestic producers and from more to less expensive foreign producers, as well as from domestic to cheaper foreign producers.

The BLS has put forward a plan for a true IPI (Alterman 2008, 2009, 2013). With an IPI, a newly imported product that matches the primary attributes of a domestically supplied product could be brought into the IPI as a directly comparable substitute. Also, in principle, the purchaser

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formula for calculating quantity shares from value shares and the discount d^1. A related formula for outlet substitution bias is found in Diewert (1998, p. 51).

[31] Houseman et al. (2011) also provide relevant empirical evidence for the IPI bias case, including pointing out evidence in studies of others about the cost savings possible to a business from switching from domestic to foreign suppliers for intermediate products. They note as well that "the foreign price deflator for intermediate materials rose somewhat *faster* than the domestic deflator" (p. 122). This result is the opposite of what, as they explain, would be the expected result and which could be explained by price index bias problems of the sort we consider here and in the previous section. They empirically implement a bias correction to an input price index under a range of alternative possible assumptions.

[32] See Yuskavage, Strassner, and Mediros (2008), Kurz and Lengermann (2008), and Eldridge and Harper (2010).

of the inputs would be able to report the price per unit irrespective of the sources for inputs they treat as homogeneous in terms of what is done with the product purchases.

However, if the current BLS practice of not averaging prices over units of a product with different prices and from different suppliers is adopted for the IPI program too, then the new IPI could also be subject to sourcing substitution bias.[33] This IPI bias could be represented using (34) in the same manner as for the PPI and MPI cases except that purchases for domestic as well as imported inputs would now be covered. For the same sorts of reasons discussed previously for the PPI and MPI, we would expect this bias problem to be positive and growing.[34]

4.6 Inflation Measurement Problems Due to the Initial Switch to Outsourcing

When a business switches from in-house production to procurement of an intermediate input, it is usually done in hopes of realizing cost savings. The fact that this sort of cost savings will not be picked up by the PPI or MPI programs is sometimes treated as an aspect of the new goods price index bias problem even if there is nothing new in terms of the input in question. We note, however, that there will usually be no way for a business to make this sort of a change without alterations to the operating processes of the business. Alternatively, therefore, this sort of sourcing change might be viewed as a business technology change that should be counted as a contribution to productivity growth. Nevertheless, regardless of which of these perspectives is adopted, this sort of change is outside the scope of this paper.

5. Five Sorts of Barriers to Adoption of Unit Values for Official Statistics Purposes

The target indexes we recommend incorporate unit values. As we have noted, there are impediments to the adoption of indexes like this by statistics agencies in their official published series. Here we deal with what we see as the main impediments grouped under five subheadings.

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[33] This point was independently noted by both Diewert and Nakamura (2010/2011) and Reinsdorf and Yuskavage (2014).

[34] An additional conceptual test is international aggregation as in Maddison (2001). The sum of the world GDP should be a consistent measure of world investment and consumption; this implies that exports and imports (with shipping costs) equate across nations in real terms. Eliminating sourcing biases moves us toward an ability to meet this test.

5.1 Impediment 1: Bad Reputation Due to Historical Misuse of Unit Value Indexes

The Price Statistics Review Committee chaired by George Stigler, also known as the Stigler Committee, considered the relative merits of unit value versus what is referred to as specification pricing and recommended the latter. Under the heading of "Specification vs. Unit Pricing," the Stigler Committee report[35] states that:

> In 1934, the Bureau of Labor Statistics adopted "specification" pricing, and since then has sought to price narrowly defined commodities and services to obtain price relatives for price indexes. … The Committee believes that in principle the specification method of pricing is the appropriate method for price indexes. The changing unit values of a *broad* class of goods (say shirts or automobiles) reflect both the changes in prices of comparable items and the shifting composition of lower and higher quality items. [italics added]

Note, however, that the Stigler Committee's opposition to unit values did not arise in the context of price collection for carefully and very narrowly specified products as we are recommending; rather, it arose in the context of prices collected for what nowadays would be viewed as very broadly specified products.

The Stigler Committee report recommended the use of probability sampling methods by the BLS, and these methods led to heterogeneous samples of items being selected. In addition, back then, the price of new cars was based on the average of what were referred to as the "low priced three" makes of automobile (Chevrolet, Ford, and Plymouth), with no adjustment for quality as the models evolved over time. The Committee report was particularly concerned that, "In the case of the Farm Indexes the classes over which unit values are computed are still often too wide" (p. 33). An accompanying study by Rees (1961) argued that the Farm Index measure of rugs, which did not specify the fiber content, failed to capture a substantial rise in the price of wool rugs reflected in the BLS data (and in Sears and Ward catalogs) because it increasingly captured the pricing of wool-rayon blend rugs (pp. 150–153).[36] Similarly, the old U.S. Census Bureau unit value indexes for imports and exports were based on customs administrative data for

[35] See the Price Statistics Review Committee of the National Bureau of Economic Research (1961).

[36] From 1948 to 1959, the relevant BLS price index services and Sears and Ward prices grew 50 percent, whereas the Farm Index series grew less than 10 percent.

very broad product categories. As a result, the Census Bureau unit value average prices were clearly subject to mix shifts.

As part of its response to the Stigler Report, in 1973 the BLS began producing rudimentary versions of an MPI and an Export Price Index (XPI) using price quotes and value share weights produced by methods similar to those used for the PPI program. Full coverage of import and export goods categories was achieved by 1982 for the MPI and XPI.[37] Nevertheless, the Census Bureau unit value indexes were not discontinued until July 1989. Alterman (1991) takes advantage of data from the overlap years to conduct a comparative empirical study of the Census unit value indexes versus the MPI and XPI produced by the BLS. That study notes that if unit values are computed for what, in fact, are different products, then those price indexes will reflect not only the underlying price changes but also any changes in the product mix. For example, he states that if there were a market shift, say, "from cheap economy cars to expensive luxury cars, the unit value of the commodity (autos) will increase, even if all prices for individual products remain constant." This clarifying remark makes it clear that Alterman, in his 1991 paper, is referring to the commodity categories the Census Bureau used in constructing its unit value indexes rather than to precisely and very narrowly defined products. Alterman's remark was true for the customs data that the Census Bureau used in constructing its unit value indexes but does not pertain to our proposals.

Alterman (1991) also reports an interesting anomaly along with his other findings:

> In comparing price trends of imported products, the BLS series, surprisingly, registered a consistently higher rate of increase between 1985 and 1989. Between March 1985 and June 1989 the BLS index rose 20.8 percent, while the equivalent unit-value index increased just 13.7 percent…. With the exception of motor vehicles, the major import components — foods, feeds, and beverages, industrial supplies and materials, capital goods, and consumer goods — *all* show larger increases in the BLS series than in the unit value series. *The most dramatic difference between the two series is found in the comparison for imported consumer goods. Between March 1985 and June 1989 the BLS series recorded a*

[37] See also Silver (2010).

30.7 percent increase, while the comparable unit-value series rose just 10.3 percent. [italics added]

As Alterman explains, his discovery that the Census Bureau unit value series show *smaller* price increases for imports than the MPI contradicts a common presumption about the nature of unit value indexes. This is the presumption that quality levels tend to rise over time so that the failure to adjust for product mix changes within the product categories for which prices are being averaged will typically cause unit value indexes based on broad product categories to overstate the true price increases.[38]

We, however, now suspect that what Alterman identified as an “anomalous” result is likely a manifestation of sourcing substitution bias in the MPI: a problem that would not have affected the Census unit value series in the same way. In particular, the MPI produced by the BLS could not capture direct cost savings that buyers achieved by switching to lower cost suppliers. In contrast, the old Census unit value series probably did capture at least some of those price-motivated buying switches among products sharing the same, or almost the same, primary attributes.[39]

5.2 Impediment 2: Questions Regarding the Proper Treatment of Auxiliary Attributes

Producers of mass marketed products try to ensure the consistency of the units of what they label as being the same commercial product. Producers usually want it to be the case that units of what they label as “a product” can be advertised and sold interchangeably. For example, a 10.75-ounce can of Campbell’s tomato soup, as defined by the company that owns the brand, is intended by Campbell’s to be the same product no matter when, where, or how a can of the soup is purchased. As noted, however, units of a homogeneous product that all have the same primary attributes can acquire different auxiliary attributes such as having been sold at regular price, during a temporary promotional sale, or at a neighborhood convenience store versus a superstore.

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[38] Alterman (1991) proposes and checks out other possible explanations as well for the results he observed, but reports that those other hypotheses were rejected by the data.

[39] Written comments by Pinelopi Koujianou Goldberg on Nakamura and Steinsson (2012), shared with us by those authors, led us to see this point, and made us aware that similar issues may affect a variety of other studies and views on changes over time in price flexibility and related issues for the US economy and for international comparisons.

And yet, when it comes to using units of a product (e.g., cans of soup or tins of tuna) purchased, say, from different outlets to take advantage of price promotions, typically no account is taken of the foregone effort or time of the family member who did the shopping in terms of how the product units are utilized. This is in line with current practices for compiling the gross domestic product (GDP). That aggregate is compiled for the U.S. by the Bureau of Economic Analysis (BEA) following the guidelines of the System of National Accounts (SNA). It is explicit in the SNA that no account is taken of unpaid time expenditures of household members, whether for picking up groceries at a superstore, rather than a nearby convenience store, or for any other activity.[40] Moreover, the nominal value of the consumption aggregate includes *all* sales of consumer products at the prices for which they were, in fact, purchased. One main purpose of the CPI program is to provide components to be used for constructing deflators for the consumption aggregate of the GDP.

We can, nevertheless, see reasons for wanting to hold a variety of auxiliary attributes constant in estimating the price relatives that are used in compiling a price index. After all, customers are willing to pay more per unit for the soup cans sold in a convenience store, and, in that sense, those cans of soup are definitely of "higher quality" than lower priced units of the product sold at a discount superstore. If that product differentiation is adopted for price quote collection purposes, however, then it is important for the auxiliary product attributes to be taken into account as well in collecting the data for and in producing the product-specific value-share weights for the price index. The question of how auxiliary product unit attributes should be treated is deep and largely beyond the scope of this paper.

5.3 Impediment 3: Producer Goods with Different UPCs but the Same Primary Attributes

The mechanics of price measurement for producer goods are greatly simplified when the products can be specified as individual product UPCs or predefined groups of these. It is the primary product characteristics that usually matter for how product units are utilized in a production process, and differences in primary attributes are always reflected in different UPCs.

[40] http://unstats.un.org/unsd/nationalaccount/

Nevertheless, UPCs for product units sometimes differ even though the product units are identical for practical purposes. For example, many large manufacturers issue precise specifications for needed intermediate products and then purposely select multiple suppliers from among the businesses that bid on the supply contract opportunity. If intermediate product units are produced according to identical specifications, but by different producers, the product units from each producer will have producer-specific UPCs regardless of whether there is any difference in any product attribute other than the identity of the producer. For price index compilation purposes, units of products that are not treated differently by the final user should usually be treated as the same product even when their UPCs may differ.

When the same product can have more than one UPC, those UPCs should be grouped together and a single unit value price should be computed for the group each period. Defining classification systems of UPCs can be a laborious process, however. In addition, if a producer indicates that the product units from different suppliers are used or sold in the same way except for some allowance for a quality difference (e.g., purchase order adjustments to allow for supplier specific defect rates), then the producer could also be asked to report and evaluate the quality difference and that information could be used in implementing quality adjustments so that the product units from the different suppliers can all be treated as units of the same constant quality product.

5.4 Impediment 4: Consumer Products Sharing Primary Attributes but Not UPCs

Concerns have also been raised regarding the inflation measurement implications of a growing proliferation of retail products with different UPCs even when the producer is the same and the primary product attribute differences are trivial. One reason for this proliferation may be that producers supplying retail products fear that their customers may switch to buying the products of competitors if they raise their prices in an obvious way. Hence, they instead bring out new versions of the product that are minor variants on existing ones: variants advertised as being new and improved and that are offered at increased prices that yield higher profit margins. The corresponding old versions may then be discontinued.[41]

[41] See Nakamura and Steinsson (2008, 2012).

Another reason for the introduction by a producer of a new product that intentionally has primary attributes that are highly similar to the attributes of an existing product may be a desire to take market share from competitors with successful products. In these cases, the producer wants the new product to differ enough from the old one to avoid successful trademark or patent infringement lawsuits but hopes that potential users will judge the new product to be the same (or better) than the old one they were purchasing. For example, large grocery store chains often introduce their own "private label" variants of popular established brand name products. Similarly, clothing makers often try to bring out styles similar to those of popular designers. And pharmaceutical companies often try to find ways of producing drugs with the same or better effectiveness as the successful drugs produced by competitors. Foreign producers seeking to break in to or expand in the U.S. domestic market are another source of products with different UPCs but that are deliberately similar to existing products in terms of the primary attributes.

Conversely, but equivalently for measurement purposes, a producer may have the goal of maintaining a constant price by replacing a product with another that is less costly to produce. Examples of the type often cited in the media would be the substitution of a slightly smaller chocolate bar or package of coffee, with a new UPC, in lieu of raising the product price. Again, such a strategy can make it difficult for the statistical agency to identify and measure the quality-adjusted price increase.

Although statistical agencies like the BLS do not average over changing sets of multiple price quotes for individual products, for price change to be measured correctly, unit values are sometimes defined in the BLS price index programs to encompass multiple UPCs that represent the same product. The task of determining when consumer products with different UPCs are, in fact, sufficiently similar that they should be treated as the same for inflation measurement purposes may be harder than the corresponding problem previously discussed for producer products. There are three reasons for this:

- Consumers are far more numerous than producers, and they generally each buy much smaller amounts than producers purchasing intermediate products. Hence, the product use views and experiences of much larger user groups would need to be considered to follow an approach for consumers like what we previously suggested for producers.

- Producers inevitably keep and analyze data about the performance of units of an intermediate product that are obtained from different suppliers. Consumers, on the other hand, are not usually in a position to systematically note primary attribute quality differences for similar product units from different producers.
- Producer products that are similar enough that it might make sense to consider them as being the same product were often *requested* by the purchaser. Thus, the attempted sameness is an openly declared objective to satisfy specifications issued by the purchaser. In contrast, sameness in the consumer case that results from an effort to expand or enter into a market by competing with the product of a competitor is usually illegal if the duplication is exact. Hence, for consumer products, design work is needed to produce a similar product that is nonetheless sufficiently different to defend against any allegations of patent infringement. Foreign suppliers trying to gain market share from domestic producers of consumer products often invest heavily in that type of product design work. Much effort can go into legally producing an almost identical product to one that is already being sold by some other producer.

Even when a very similar new product is developed by a producer as an alternative for one of their own established products, perhaps in the hopes of being able to use the new product as a means of making a de facto price adjustment, design work is usually required. This is the case no matter how small the differences may seem in terms of the primary product attributes. From some perspectives, product development should be treated as part of productivity growth rather than as a price change mechanism. Hence, maybe these products truly should be treated as new products rather than as quality adjusted old products. Kaplan and Menzio (2014) offer data on the distribution of prices across similar products as well as within UPCs; their analysis sheds some light on the relative importance of alternative product specification methods. However, we do not attempt to provide answers here to these difficult questions.

Nevertheless, the issue of when and how to average prices over units of consumer products with very similar primary attributes, as is now sometimes done on the consumer side using hedonic and other quality adjustment methods, must be faced whether or not our recommendation to use unit value price indexes is adopted. The BLS is already engaged on an ongoing basis in deciding when different product versions are similar enough to be treated as the same thing, and those important efforts are outside of the scope of this paper and are not covered here.

5.5 Impediment 5: A Need to Change Current Data Collection Arrangements

The most straightforward impediment to conquer might be the most serious. The information requirements for a unit value price approach based on narrowly defined products are much larger than for the approaches used for conventional price indexes. Nevertheless, private businesses have paved the way. Businesses formerly carried out their decision-making and forecasting using samples and other sorts of incomplete information for their own transactions. In contrast, modern big businesses strive to operate with full, real-time transactional visibility.

Thus, the nature of the needed changes at the BLS and other national statistics agencies can be seen from the way in which large private sector businesses have remade their data systems over the recent decades and have then also remade their business processes to utilize their improved information capabilities. The needed hardware and software have been developed. Nevertheless, moving a national statistics agency into a position of roughly equivalent data storage and handling capabilities with what big companies now have will require large budget allocations and substantial investments in training and hiring people with the needed capabilities. Private sector data system experts do not have official statistics expertise, and those already with the statistical agencies have had no opportunity to master data capture, warehousing and utilization methods of the sort that have become common for big businesses, or the intricacies of Universal Product Codes (the UPCs).[42]

It is instructive to briefly examine the steps that the private sector had to take to attain its modern data handling capabilities. The 1961 Stigler Report was written before the business world had UPCs. Indeed, for most of this century, as stores grew bigger and varieties multiplied, the only way for a grocer or other retailer to find out what was in stock was by physically counting all the cans, boxes, and bags. The achievement of widespread use of UPCs was the result of sustained business world efforts of many sorts. A machine-readable product code design

[42] There is an even larger knowledge gap opening up between the business world and the official statistics agencies as the business world now begins to move from UPCs and barcode scanners to Electronic Product Code (EPC) and Radio Frequency Identification (RFID) usage. See Roberti (2005) for more on the nature and reasons for this continuing evolution.

had to be devised and agreed upon. Equipment for cost effectively reading the product codes and for storing and processing the product code data had to be invented, produced, purchased, and put to use by businesses. A product code numbering system also had to be invented and agreed upon. And an organization had to be developed to oversee the assignment and use of product codes. Also, business processes had to be redesigned to make use of the product code data.

More than a decade before the Stigler Report was written, Bernard Silver and Norman Joseph Woodland developed and were granted a patent in 1952 for a barcode design consisting of concentric circles that could be scanned from any direction. However, without an inexpensive, fast, and convenient way to read and record barcode data, their invention could not be put to applied use. The development of inexpensive lasers and integrated circuits in the 1960s made barcode scanners and barcode data handling potentially affordable for retailers. However, the original Silver-Woodland "bull's-eye" barcode design performed poorly in an important field test. Also, there was the challenge still to be met of getting all needed participants to move forward together.

In the early 1970s, IBM researcher George J. Laurer devised a new barcode design for which the field test results were acceptable. He then succeeded as well in getting the U.S. Supermarket Ad Hoc Committee interested in what was named the IBM Uniform Product Code (UPC) system.[43] On April 3, 1973, the Ad Hoc Committee voted to accept the symbol proposed by IBM.

Standardization made it worth the expense for manufacturers to put barcodes on their packages and for printers to develop the needed new ink types, plates, and other necessities for reproducing the code with the accuracy required for the UPC scanners, and the Ad Hoc Committee succeeded in bringing the grocery industry and other needed participants together to implement UPC scanning at the point of sale (POS). This included agreement on a standardized system for assigning and retiring barcode product numbers. The nonprofit Uniform Code Council (UCC) was established. Businesses applied for registration with the UCC, which eventually changed its name to Global Standards One (GS1).[44] Each business that was accepted

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[43] The Ad Hoc Committee consisted primarily of presidents, vice presidents, and CEOs who were selected from manufacturers, distributors, and retailers to ensure that the interests of all parts of the grocery supply chain were represented. In addition to being corporate executives, the individuals selected for the committee had significant knowledge, respect, and influence within the entire industry.

[44] http://www.upccode.net/upc-guide/uniform-code-council.html

as a registered member began paying an annual fee and was then issued a manufacturer identification number and given training on how to register their products and to assign and retire UPCs as needed.

Use of scanners grew slowly at first. In 1978 less than 1 percent of grocery stores nationwide had scanners. By mid-1981, the figure was 10 percent. Three years later, it was 33 percent. And by 1999, it was already over 60 percent.[45]

GS1 today manages what is collectively referred to as the Global Trade Item Number (GTIN) System which includes the UPCs.[46] The official GS1 member organization for the U.S. is now called GS1 US. The modern logistics, inventory management, and pricing and advertising operations of businesses of many sorts, especially grocers and general merchandise retailers, would be inconceivable without the information derived from tracking product units identified by UPCs.

In 1999, the Supermarket Ad Hoc Committee commissioned PriceWaterhouseCoopers to make a report examining the extent to which the claims of the original Ad Hoc Committee business plan had materialized (Garg, Jones, and Sheedy, 1999). The resulting report finds that the direct savings from barcode adoption proved greater than originally projected (i.e., savings at the checkout counter). The report also finds, however, that it was the general merchandise companies that managed to most fully realize the projected *indirect* savings from barcode scanning rather than the supermarkets and argues that the supermarkets have been losing market share to superstores because of this reality. The indirect savings, which had been envisioned by the original Ad Hoc Committee, pertain to business functions such as inventory management. We see Walmart as the most notable example of this last point.

From 1973 on, as grocery and other retail chain stores grew, the chains almost all established semi-autonomous regional data centers that collected and processed barcode scanner data. The reason for the regional data centers that most chains created and many still have is that the volume of the barcode data seemed too large for processing in a single data warehouse for even a mid-size chain store. Nevertheless, Walmart built an initial *companywide* data warehouse in 1979 (Metters and Walton, 2007). Walmart was also the first large retailer to give its suppliers POS and inventory data for their products, thereby helping them reduce costs due to under- or

[45] For more on this history, see Kennedy (2013).

[46] http://www.gs1.org/epcglobal/about

overproducing. Walmart recognized that by sharing this information with its supply chain partners, they could all gain from improved coordination.

To improve the reliability of access to its data warehouse, Walmart also built the world's largest private sector satellite communications system in 1987. Then in 1991, the company reportedly spent $4 billion more to create its new Retail Link companywide data warehouse. Nowadays, Walmart suppliers are able to monitor in almost real time how their products are selling on Walmart store shelves everywhere that Walmart carries its products. The POS data is credited with enabling Walmart suppliers to reduce their inventories, shorten their lead times, and increase their profitability. Also, with product items being electronically identified at the checkout counters and with financial as well as physical inventory records being updated on an ongoing, almost real-time basis, store managers in Walmart outlets everywhere as well as those in the company headquarters can plan better.

Investments that bring the data capabilities of official statistics agencies more into line with what big companies have would pay big dividends.[47] Our reform suggestions are presented in the final section. However, before proceeding to those suggestions, we briefly note how price indexes affect some other key economic performance metrics.

6. Inflation Measurement Effects on Other Economic Performance Measures

Price indexes are used to measure inflation for nations and to transform nominal into real values. Real values of national output are then used to measure economic growth and to create measures of productivity growth and growth in material well-being over time.

Previously, we defined R^t in (1) as the sum of *either* the nominal period t revenue for all products sold by some economic entity or the nominal period t remittance paid (i.e., the cost) for all products bought by a given economic entity. However, outputs need to be distinguished from inputs for productivity and economic well-being measurement purposes. Productivity is a measure of the efficiency of an economic entity in turning inputs into desired outputs (see e.g., Diewert, 2007, and Diewert and Nakamura, 2007), and economic well-being is usually gauged by restating in per capita terms a measure of the total output for a nation (like GDP).

[47] Walmart's superior information systems have even enabled the company to respond better to emergencies such as hurricanes than government agencies, as was widely reported during Hurricane Katrina (see, e.g., Barbaro and Gillis, 2005).

For some given economic entity, here we redefine R^t, p_n^t, q_n^t and the index limits of N and J as pertaining just to *output* products (rather than including inputs too as in our previous definitions). Thus, the total nominal revenue in period t for a specified economic entity is now given by

$$(44) \qquad R^t = \sum_{n=1}^{N} R_n^t = \sum_{n=1}^{N} \sum_{j=1}^{J_n^t} p_n^{t,j} q_n^{t,j}.$$

And here we redefine $P^{0,1}$ as an index measure of *output* price change from $t=0$ to $t=1$.

The most commonly used productivity performance metric for nations is labor productivity growth. Suppose L^t is defined as a pure quantity measure of labor services input such as aggregate hours of work. Labor productivity growth from period 0 to 1, denoted here by $LP^{0,1}$, can be measured as the ratio of real revenue growth to a growth ratio for aggregate hours of work:

$$(45) \qquad LP^{0,1} = \frac{(R^1/R^0)/P^{0,1}}{L^1/L^0}.$$

The interpretation people want to make of labor productivity values is that values greater than one (less than one) mean that real GDP has grown faster (slower) over time than the quantity of labor required to produce the real output.

We now consider how the price index bias problems discussed in previous sections of this paper could distort measures of real GDP growth. Nominal GDP for period t is defined as

$$(46) \qquad GDP = C + I + G + (X - M),$$

where C denotes aggregate consumption, I is investment, G is government expenditure, X is exports, and M is imports. If inflation is overestimated (underestimated) for the C component of GDP, this will cause the growth of real GDP to be underestimated (overestimated) since C enters with a positive sign into GDP. If inflation is overestimated (underestimated) for the M component of GDP, this will cause the growth of real GDP to also be *over*estimated (*under*estimated) since M enters with a negative sign into GDP.

The outlet substitution bias problem explained in Section 4.1 is believed to have contributed to the overestimation of inflation for C, and hence to the underestimation of real GDP growth. The MPI sourcing substitution problem explained in Section 4.3 is also believed to have contributed to an overestimation of inflation, for imports in this case, but this would contribute to an overestimate, rather than an underestimate, for GDP growth because M enters the expression for GDP with a negative sign.[48]

The extent to which these bias effects on real GDP cancel each other out is an empirical question. Although for the U.S. the C component of nominal GDP is much larger than the M portion, there are fairly narrow limits on the proportion by which it makes sense for a retailer selling in any given market area to undercut the prices of competitors. This places bounds on the likely size of the CPI outlet substitution bias problem. In contrast, intermediate product supply contracts can be very large, and suppliers sometimes have labor, raw materials access, patent, government subsidy, or other cost advantages that make it possible for them to profitably sell their products, if they wish, at prices far below what competitors are charging. Hence, it is plausible that positive MPI bias problems have outweighed positive CPI bias problems, resulting in the systematic overestimation of real GDP growth. There is an urgent need for empirical research on this point.

Haskel, Lawrence, Leamer, and Slaughter (2012) paint a vivid picture of real income declines for the large majority of Americans over the previous decade. They classify U.S. workers into five groups by their levels of education: five groups that *all* enjoyed substantial increases in average real income in the second half of the 1900s. However, since 2000, these same groups of workers suffered real average income declines. This is perplexing, Haskel et al. note, since the U.S. economy had superior measured labor productivity growth.[49] They point out that the last 10 to 15 years have also brought dramatic changes in economic globalization but that connections between globalization and the observed economic trends are unclear based on available research. Our own results, considered along with other findings cited in our paper, raise the possibility in our minds that price index bias problems that have been indirectly worsened by the growth of electronic information processing and communications and associated business

[48] We focus on just the bias problems for the CPI and MPI here because those bias problems affect the computation of real GDP. In contrast, whereas bias problems for the PPI or the proposed IPI are relevant for the estimation of real input values for intermediate products, these problems do not affect in any direct way the computation of official real GDP estimates, and, hence, do not directly affect the labor productivity growth estimates of official statistics agencies like the BLS. Houseman (2007, 2009, 2010, 2011) and Mandel (2007, 2009) have explored and helped raise interest in these issues. See also Strassner et al. (2009), Fukao and Arai (2013), Inklaar (2012), and Howells et al. (2013).

[49] Haskel et al. (2012) refer to the BLS data series #PRS85006092 at http://www.bls.gov.

process changes (changes that enabled globalization) may, in part at least, be responsible for the perplexing picture of how the U.S. economy has been doing that Haskel et al. report.

We conclude with suggested changes in official statistics price measurement that we feel could improve this situation.

7. Possible Price Measurement Practice Reforms

We have shown that the bias formulas derived in this paper can be used to represent the sourcing substitution bias problem in the MPI and in the PPI or in the proposed IPI,[50] as well as the outlet substitution and promotions biases in the Consumer Price Index (CPI). Our recommendations in this final section are aimed at reducing the noted bias problems.

Our main recommendation is that when the same product is sold at multiple prices during a time period, the conventional practice of using a single price observation per period on a product in a given establishment to represent each price distribution during the time period should be replaced by the use of unit value prices. Hence, we argue for greater adoption of unit value-based price indexes to handle cases of multiple prices for the same product in the same period. This implies a need for modifications of data collection operations and compilation procedures. In the text, these modifications are part of what we allude to as the fifth and most serious of the impediments to the adoption of unit value-based price indexes. We propose a way here in which the BLS might proceed incrementally toward a capability for unit value-based price index compilation.

At present, the BLS price quote collection operation for the CPI, PPI, and MPI starts with selecting establishments on a probabilistic basis from comprehensive lists of various sorts, and then proceeds with the selection of products on a probabilistic basis at each selected establishment. Then, the BLS collects a single price quote each pricing period (typically a month) for each selected product at each of the selected establishments.[51] The way product versions are selected for pricing at different establishments does not usually result in the same product version being chosen for price collection at multiple business establishments. Moreover, even when the BLS price collection approach does yield multiple price observations for the same

[50] See Alterman (2008, 2009, 2013).

[51] So, if an establishment, in fact, charged or paid multiple per unit prices for a chosen product in a given month, there will be no evidence of this in the BLS price quote data.

product version, the BLS does not average over changing sets of the price observations.[52] In addition, for producer products, an effort is made to only make price comparisons over time for the same buyer-seller pairs. These are the main reasons why the BLS price collection operations could not, at present, support a switch to compiling unit value-based price indexes.

Yet, most businesses in a developed country such as the U.S. have their full transactions data for at least the current month readily available in electronic form. Hence, with equal ease, a business *could* give the BLS the quantity of the selected product that was bought or sold along with the price per unit that the BLS presently collects. Feenstra and Shiells (1996) made this recommendation almost 20 years ago. Moreover, most modern businesses could provide their quantity as well as price data for all transactions over some recent time period, such as a month, for a list of UPC-identified products. Moreover, the respondent burden would barely vary depending on the length of the product list. Hence, perhaps the same basic probabilistic selection approach for products at each selected establishment could be retained, but the products selected at each establishment could be added to *a common product list for all establishments*, and then a month worth of transactions data could be obtained from *all* selected establishments for *all* products on the common list.[53] The BLS would then have the option of producing various sorts of unit value price indexes.

If the averaging of prices for UPC-identified products is done over time, month by month, for each establishment, it should be possible to produce unit value-based price indexes that are largely free of promotions bias problems. However, the outlet substitution bias would remain so long as there is no averaging over establishments. Alternatively, if the averaging of prices for UPC-identified products is carried out for establishments in each designated geographical area as well as over time, month by month, then it should be possible to produce unit value-based price indexes that are largely free of outlet substitution as well as promotions bias problems.

Unfortunately though, even averaging over establishments and time will not help with MPI and PPI bias problems because units of intermediate products are often bought from multiple suppliers and product units from different producers have different UPCs even if all other primary attributes are identical. Thus, the sourcing substitution bias problem would remain.

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[52] As noted above, the geometric mean indexes used in the CPI amount to averaging prices, but the sample of prices that are averaged is held constant between the two time periods being compared. In contrast, unit value indexes allow the composition of the averages to change.

[53] It is important for this sampling to include Internet and multichannel retailers (Metters and Walton, 2007).

Nor would this averaging of prices help with the product replacement bias phenomenon identified by Nakamura and Steinsson: This is another important case in which the UPCs differ for product items with essentially the same primary attributes.

At least for producer intermediate products, however, the user of the intermediate product units is in a position to specify the UPCs that are for the same product from their perspective. Hence, we recommend asking all producers from whom price quotes are collected if they regard some of the UPC-identified products they purchase as identical in that they use the product units interchangeably and in identically the same manner. Moreover, if a producer indicates that the product units from different suppliers are used or sold in the same way except for some allowance for a quality difference (e.g., purchase order adjustments to allow for supplier specific defect rates), then the producer could also be asked to report and evaluate the quality difference, and that information could be used in implementing quality adjustments so that the product units from the different suppliers can all be treated as units of the same constant quality product.

As we have noted, there are also four other sorts of impediments to the adoption of unit value-based price indexes by an official statistics agency like the BLS. One is an established and somewhat indiscriminant prejudice against unit values. We have argued that the reasons that led to this prejudice do not apply when the unit values are for UPC-identified or similarly very narrowly defined products, which is what we recommend.[54]

We differentiate what we call primary product and auxiliary product attributes. We define *primary product attributes* as characteristics a product unit has when first sold by the original producer and that continue to be characteristics of the product unit regardless of where and how it may be resold. We define *auxiliary product unit attributes* as attributes that a product unit acquires as a consequence of where and how it is sold. A second impediment we then identify is that some of what a producer ships out as units of the same product can acquire additional auxiliary price determining attributes depending on where and how the product units are sold. We note that there are difficult conceptual and operational questions that arise regarding the treatment of those auxiliary product attributes.

We can, as already acknowledged, see reasons for wanting to hold a variety of auxiliary attributes constant in estimating the price relatives that are used in compiling a price index.

[54] Indeed, the UPC-identified products may be too narrowly defined in some cases so sometimes it may be judged to be better for inflation measurement purposes to treat a stated group of UPCs as all for the same product.

However, if an auxiliary attribute is used in product differentiation for price quote collection purposes, then it is important for that same auxiliary product attribute to be taken into account too in collecting the data for and in producing the product-specific value-share weights for a price index.

A third impediment is that there are unresolved issues regarding the price measurement appropriateness and the operational difficulty of recognizing the sameness of units of producer intermediate inputs from different suppliers that are viewed as identical (or almost so) by the businesses using these inputs. Related issues arise as well for consumer products, and we label those issues as the fourth impediment. So, both impediments 3 and 4 relate to situations where the UPC product definitions may be narrower than ideal for inflation measurement purposes. We view the task of determining when units of consumer products with different UPCs are, in fact, the same or sufficiently similar that they should be treated as the same for inflation measurement purposes as intrinsically harder than the corresponding problem discussed previously for producer products.

Clearly, we do not provide full solutions to all the problems noted,[55] and some of our proposed solutions may prove to be suboptimal. We offer these suggestions in the spirit of a search for better ways that we believe possible now given product code and other modern information technology developments.

The incremental new transactions data collection approach outlined above would allow estimates to be made of the importance of the identified price index bias problems, since this recommended approach nests the current BLS price quote collection processes. The BLS could also draw on the growing experiences of other national statistics agencies that are now producing unit value-based price indexes based on electronic data from businesses (though, as we understand, without designating them as different from the conventional price indexes or explaining the relationship).[56]

[55] For example, we have not made a start even on considering the problems of producing unit values for products such as computers that are currently handled using hedonic methods (see, for example, Baldwin et al., 1996; Berndt and Rappaport, 2001; Pakes, 2003; and Pakes and Erickson, 2011), or pharmaceuticals and medical services (Berndt and Newhouse, 2012).

[56] The Australian Bureau of Statistics and the New Zealand Bureau of Statistics have been reportedly exploring ways of obtaining supermarket scanner data directly from the main supermarket chains in those nations and then of using weekly unit value prices for grocery products that are computed by the statistical agencies directly from grocery store scanner data. Also, as Guðmundsdóttir, Guðnason, and Jónsdóttir (2008) explain, Statistics Iceland

We also note that the suggested incremental new data collection approach would vastly enrich the BLS research databases, in addition to contributing to the price index improvement agenda. Price indexes are ubiquitously used as measures of inflation and as deflators. In addition, however, the BLS research databases have been enabling a true empirical examination of the origins and transmissions of price signals in the U.S. economy.[57] If the BLS is given the resources[58] needed to harness the power of the new information technologies, including the product codes now ubiquitously used by businesses, and if our recommendations are accepted, we believe the eventual result will be far superior price indexes and great improvements as well in the accuracy of the host of other economic measures that embed price indexes as component parts, and an even greater flowering of insights into price signals, which are fundamental to the functioning of a free market economy.

Appendix A: Putting the Picture Together with a Final Example

The BLS collects and uses prices for the CPI regardless of whether they are "regular" or "sale" prices. In contrast, as noted in the text, some U.S. trading partners, like Japan and the EU countries, exclude sale prices when compiling their CPI programs. A numerical example may help clarify why this choice matters. Consider the Table A-1 hypothetical data.

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collects electronic data from the information systems of firms. Besides prices and quantities, the data Statistics Iceland harvests show customer identifiers and business terms for each customer at the time of the trade. Statistics Iceland reports that electronic data collection has resulted in lower collection costs and lighter response burdens for the participating firms. Statistics Iceland also reports that when the agency switched to electronic data collection from firms, it was also able to adopt a superlative approach for price index compilation. Feenstra, Mandel, Reinsdorf, and Slaughter (2013) analyzed several sources of mismeasurement in the U.S. terms of trade and found that one important source of bias comes from the fact that the import and export price indexes published by the BLS are Laspeyres indexes, rather than being based on a superlative formula.

[57] The CPI Research Database is a confidential data set that contains all the product-level nonshelter price and characteristics data that were used to construct the CPI from 1988 to the present. The goods and services included in the CPI Research Database represent about 70 percent of consumer expenditures, the excluded categories being rent and owners' equivalent rent. Nakamura and Steinsson (2008, 2012) created analogous data sets from the production files underlying the PPI and the MPI and XPI. Those data sets have become the new Research Databases for the PPI and international prices program. These BLS research databases are enabling far-reaching and fundamental advances in economic understanding.

[58] It is possible that more than financial resources will be required. Participation in all BLS price surveys is voluntary, unlike the situation in many nations, and some businesses may consider the provision of electronic price and quantity data to be more burdensome than the current BLS data collection procedures.

Table A-1. Regular and Temporary Sale Transactions Data for a Product

	Price ($)	Quantity	Transaction Value ($)
		Period ($t=0$)	
1. Regular price transactions for product n	2.00	2,000	4,000
2. Temporary sale discount price transactions	1.00	3,000	3,000
3. Total		5,000	7,000
		Period ($t=1$)	
4. Regular price transactions for product n	2.20	1,000	2,200
5. Temporary sale discount price transactions	1.15	4,000	4,600
6. Total		5,000	6,800

Case 1. Suppose that only the regular price quotes are used for compiling a price index. As for the estimates of the value weights, following conventional practice, suppose these come from a household survey that does not distinguish between regular and sale transactions and will reflect all transactions for a product. With the hypothetical data in rows 1 and 4 of Table A-1 for regular price transactions, the resulting Laspeyres, Paasche, and Fisher price indexes all equal 1.1.[59]

Case 2. Next, suppose that both the regular and sale prices are used, treating the items of product n sold at regular price as a different product from the items sold during temporary sale periods. If we do that, we get[60] $P_L^{0,1}=1.121$, $P_P^{0,1}=1.333$, and $P_F^{0,1}=(P_L^{0,1}P_P^{0,1})^{1/2}=1.127$.[61] Note that only the quantities of the product sold at regular price are used now as weights for the observed regular price quotes, and only the quantities of the product sold at a temporary sale price are used as weights for those price quotes, which is what one might expect to be the procedural implication of treating the two groups of units of the product as *different* products.

59 $P_L^{0,1}=\frac{\$2.20\times(2{,}000+3{,}000\text{ items})}{\$2.00\times(2{,}000+3{,}000\text{ items})}=1.1$, $P_P^{0,1}=\frac{\$2.20\times(1{,}000+4{,}000\text{ items})}{\$2.00\times(1{,}000+4{,}000\text{ items})}=1.1$, and $P_F^{0,1}=(P_L^{0,1}P_P^{0,1})^{1/2}$.

60 We note again that the US CPI actually would employ a geometric mean, rather than Laspeyres, formula.

61 $P_L^{0,1}=\frac{(\$2.20\times2{,}000\text{ items})+(\$1.15\times3{,}000\text{ items})}{(\$2.00\times2{,}000\text{ items})+(\$1.00\times3{,}000\text{ items})}=1.1$, $P_P^{0,1}=\frac{(\$2.20\times1{,}000\text{ items})+(\$1.15\times4{,}000\text{ items})}{(\$2.00\times1{,}000\text{ items})+(\$1.00\times4{,}000\text{ items})}=1.3$.

Case 3. Finally, suppose we treat each unit of a product as being the same regardless of whether it is sold at regular price or at a discount during a temporary sale period. In this case, we first compute the average price for the product n in each period:

$$\overline{p_n^{0,\bullet}} = \frac{\$4{,}000 + \$3{,}000}{2{,}000 + 3{,}000} = 1.4 \quad \text{and} \quad \overline{p_n^{1,\bullet}} = \frac{\$2{,}200 + \$4{,}600}{1{,}000 + 4{,}000} = 1.36 .$$

Using the average prices for the price variable and the total transactions volumes for the quantity variable in each price index, now we get $P_L^{0,1} = P_P^{0,1} = P_F^{0,1} = .9714$.[62]

In period 0 and in period 1, the quantity of 5,000 units of product n was transacted. These transactions had a nominal value of \$4,000 in period 0 and \$6,800 in period 1. If we deflate the period 1 nominal value by .9714, we get a *real value* of \$7,000, so we find no change in the real value from period 0 to 1: a result that is in agreement with the data on the physical quantities transacted. This result only pertains to the last of the previous approaches for calculating a price index; the others do not yield this outcome.

Appendix B: An Example Showing How Product Definitions Matter

The producer-side product substitution bias problems identified by Nakamura and Steinsson and the sourcing substitution bias problems identified by Diewert and Nakamura (2010) have in common the fact that the solutions to both necessarily involve some sort of averaging of per unit prices for products with different UPCs. As already noted, these bias problems force a consideration of how products are defined.

UPCs have the desirable attributes of being documented and electronically recognizable. Also, business data systems are built to keep track of product purchases and sales using UPC information, making it easy for businesses to provide information to statistical agencies for products identified by UPCs.

Consider the case of an economy with just two commercially distinct output products: A and B. We will briefly examine the measurement consequences of treating the two products as distinct for both price and value share data collection purposes versus grouping them together as a single product. We will assume we have full price and quantity data for all transactions for the

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62 $P_L^{0,1} = \frac{\$1.36\times(2{,}000+3{,}000 \text{ items})}{\$1.40\times(2{,}000+3{,}000 \text{ items})} = .971$ and $P_P^{0,1} = \frac{\$1.36\times(1{,}000+4{,}000 \text{ items})}{\$1.40\times(1{,}000+4{,}000 \text{ items})} = .971$.

two products in both periods $t=0$ and $t=1$ and that there truly is just one price per product in each time period.

In row 1 of Table 1, we show the nominal output growth ratio. Below that on the left-hand side, we show the Fisher price index, the real output growth ratio created by deflating the nominal revenue ratio by the Fisher price index (which equals the Fisher quantity index), and the Fisher labor productivity index. (The results if a Laspeyres price index is used instead can be seen by ignoring the second term in the left-hand column and not taking the indicated square root in both row 2 and row 3 and in the numerator in row 4.)

The counterpart expressions that are obtained if we use the same full transactions data but treat products A and B as the same product for measurement purposes are shown on the right-hand side of the table. The nominal revenue ratio is shown in the middle of row 1 because it is unchanged by whether we treat products A and B as distinct or as the same product for measurement purposes.

The consequences of choices made about product definitions are clearest perhaps from the quantity growth ratios in row 3. When we distinguish the products, the quantity growth measure involves price weighted aggregates; whereas, when we treat the units of A and B as all being units of the same product, then the numbers of units of each are simply added in to the total for each period without the use of weights.

Table B-1. The Consequences of Treating Two Products as Distinct Versus the Same

	Using a Fisher price index for deflation with A and B treated as separate products	Using a Fisher price index for deflation with A and B treated as the same product
1	$\dfrac{R^1}{R^0}=\dfrac{p_A^1q_A^1+p_B^1q_B^1}{p_A^0q_A^0+p_B^0q_B^0}$	
2	$P_F^{0,1}=\left[\left(\dfrac{p_A^1q_A^0+p_B^1q_B^0}{p_A^0q_A^0+p_B^0q_B^0}\right)\left(\dfrac{p_A^1q_A^1+p_B^1q_B^1}{p_A^0q_A^1+p_B^0q_B^1}\right)\right]^{(1/2)}$	$P_F^{0,1}=\dfrac{(p_A^1q_A^1+p_B^1q_B^1)/(q_A^1+q_B^1)}{(p_A^0q_A^0+p_B^0q_B^0)/(q_A^0+q_B^0)}$

		$= \left(\frac{R^{1}}{R^{0}}\right)\left(\frac{q_A^0 + q_B^0}{q_A^1 + q_B^1}\right)$
3	$\left(\frac{R^{1}}{R^{0}}\right) / P_F^{0,1} = \left[\left(\frac{p_A^0 q_A^1 + p_B^0 q_B^1}{p_A^0 q_A^0 + p_B^0 q_B^0}\right)\left(\frac{p_A^1 q_A^1 + p_B^1 q_B^1}{p_A^1 q_A^0 + p_B^1 q_B^0}\right)\right]^{(1/2)}$	$\left(\frac{R^{1}}{R^{0}}\right) / P_F^{0,1} = \frac{q_A^1 + q_B^1}{q_A^0 + q_B^0}$
4	$LP_F^{0,1} = \frac{\left[\left(\frac{p_A^0 q_A^1 + p_B^0 q_B^1}{p_A^0 q_A^0 + p_B^0 q_B^0}\right)\left(\frac{p_A^0 q_A^1 + p_B^0 q_B^1}{p_A^0 q_A^0 + p_B^0 q_B^0}\right)\right]^{(1/2)}}{\left(L_A^1 + L_B^1\right) / \left(L_A^0 + L_B^0\right)}$	$LP_F^{0,1} = \frac{\left(\frac{q_A^1 + q_B^1}{q_A^0 + q_B^0}\right)}{\left(L_A^1 + L_B^1\right) / \left(L_A^0 + L_B^0\right)}$

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