Bias in the Import Price Index Due to Outsourcing: Can It Be Measured?[1]

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Abstract

In this paper we present new measures for the bias in an import price index due to outsourcing. The measure is developed first for a highly simplified case for the purpose of conveying the rationale for the measure. It is then generalized, yielding a meaasure that could be used in empirical studies. Before taking up this bias measurement problem, however, we explain the measurement context. This contextual material makes it clear that the growth of outsourcing and offshoring poses mutliple interrelated problems for official statistics agencies.

JEL C43, C67, C82, D24, D57, E31, F1

Key Words Offshoring, outsourcing, consumer price indexes, producer price indexes, intermediate input price indexes, bias in price indexes, Fisher index, total factor productivity growth, production accounts, System of National Accounts, exports and imports in the input output accounts.

1. Introduction

In June of 2007, *Business Week's* chief economist, Michael Mandel turned a mass media spotlight on the U.S. import price data: a problem that had come to his attention as a consequence of research by Susan Houseman (2007).[2] Mandel explained in terms that law makers and the public could understand how price index problems could result in the creation of phantom GDP. The gist of the argument is that key measures of inflation for the United States, which feed into multiple productivity and other national performance measures, miss input cost savings associated with the growth of off-shoring. By now, there is serious concern and active research regarding possible bias problems with price index and other economic performance measures for the nation due to domestic outsourcing as well as off shoring.[3] The original

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[2] Houseman (2007) explains how the failure to measure off-shoring related input price declines can result in an underestimation of real input utilization and an overestimation of the growth of U.S. gross domestic product (with the creation of phantom GDP) as well as in an overestimation of labor and multifactor productivity growth. Houseman argues that phantom GDP may be part of the explanation for why U.S. workers did not benefit more as the measured productivity of the U.S. economy grew.

[3] As Jarmin, Krizan and Tang (2009) explain: "The practice by which firms transfer all or part of their production to another company is called 'outsourcing' if the partner business is domestic and 'offshoring' if foreign." More specifically, outsourcing occurs when firms shift service and manufacturing activities to unaffiliated domestic establishments or to unaffiliated or affiliated establishments in foreign countries. Off-shoring occurs when firms

contribution of this paper is to show how price index bias problems attributable to input source substitution can be represented theoretically, and could potentially be measured.

We begin in section 2 with the Michael Mandel (2007) critique. In section 3, we briefly review some specifics of how the U.S. Import Price Index and Export Price Index of the International Prices Program are produced, as well as key features of how the Consumer Price Index and Producer Price Index are compiled. The role of the U.S. Integrated Annual Input-Output (I-O) tables in productivity measurement for the United States is also explained in section 4. The price index bias problems that are the focus of this paper are introduced in non-technical terms in section 5.

In section 6, we show how the bias due to outsourcing be measured. We first consider the simplified case of domestic outsourcing and then, subsequently, we note the modifications that are needed to deal with the case of offshore outsourcing. We consider a very simple case where there are four firms in the domestic economy producing and using a single homogeneous commodity. Firm 1 is a domestic high cost producer of the commodity that sells this output to Firm 3 in periods 0 and 1. Firm 2 is a domestic low cost producer of the commodity and it sells its output to Firm 4 in both periods. Firm 3 is a domestic firm that uses the output of the high cost firm in period 0. However, in period 1, firm 3 switches some or all of its purchases of the homogeneous commodity to the low cost Firm 2; thus Firm 3 is the outsourcing firm, and Firm 4 is a domestic firm that uses the output of the low cost Firm 2 in both periods as an input. We consider the value flows among the firms. This result is then extended in appendix A to the multi firm case. Related price index bias measures developed by Diewert in a 1998 paper are outlined in appendix B. In section 7 we share some related concluding throughts on the measurement issues raised in this paper.

2. The Michael Mandel Critique

In the scenario outlined by *Business Week's* Michael Mandel, an established U.S. company decides to outsource its former domestic production activities to a foreign company. The decision of the company to both outsource and off-shore all of its production operations was taken because this lowers the cost to the company of obtaining the product that the company sells. The claim is that in attempting to restate the cost of the off-shored intermediate input in constant, base period dollars, the statistical agency underestimates the extent of the input cost reduction, with this understatement resulting in an overestimate of the contribution of the firm to U.S. gross domestic product (GDP) and, all else equal, in an overestimate of the growth of U.S. GDP and productivity.

The parts of Mandel's 2007 *Business Week* article of greatest relevance to the issues considered in this paper is reproduced in box 1.

shift service and manufacturing activities abroad to unaffiliated firms or their own affiliates. In-shoring occurs when foreign firms shift service and manufacturing activities to firms in the United States that are affiliated or unaffiliated.

Box 1. Michael Mandel (2007) on Price Measurement and Phantom GDP

"Let's walk step by step through an example. Suppose that in 2000 a North Carolina factory made a dining room table for $1,500. At the time, a factory in China could make the same table, but not cheaply enough or quickly enough to take business away from the American factory.

Fast-forward to today. The ... Chinese factory can sell the table for $1,000 in the U.S., including shipping. The American company closes its factory and starts buying from China. U.S. consumers are still buying the same tables as before....

How does this look to the government statisticians? They attempt to calculate the "real" value of consumption by measuring how much consumers spend on tables at different times and adjusting for the changes in price. Then they do the same for "real" imports. In this example, real domestic production is more or less the difference between the real value of consumption and the real value of imports....

Now, back to the dining room table. Between 2000 and 2007, the statisticians see that consumer spending on tables has dropped by one-third and that the price has dropped by one-third (assuming all savings are passed along to consumers with no markup for profits). "Aha," they say to themselves, "The price drop accounts for all the change in spending, so the real value of consumer spending hasn't changed." They type in their spreadsheets that the table is worth $1,500 to consumers in 2007, measured in inflation-adjusted 2000 dollars. After all, it's the same table as the ones made in 2000.

Here's the rub. The statisticians need to apply their inflation-adjustment magic to the imported table as well. But the folks at the BLS import price office ... have never seen that table before.... So instead of figuring in a price drop of one-third for the imported table, they assume a much smaller price decline or perhaps no price drop at all. When they tally it up, they give the imported table a value of about $1,000, measured in inflation-adjusted 2000 dollars.

Their method leads to a serious mistake. The real value of imports looks less than the real value of consumption, by $500. After applying an arcane statistical adjustment, the government would report domestic production of roughly $250, even though no furniture production has taken place in the U.S.

This happens over and over as production of new types of goods and services moves offshore."

William Alterman (2009) of the U.S. Bureau of Labor Statistics (BLS) explains that although BLS was aware of the potential data gaps that are pointed out by Mandel (2007) and by Houseman (2007), shifts over time between domestic and foreign production had previously seemed gradual enough that the potential price index problems were not judged by BLS to be a serious concern. He notes also that this potential bias problem has presumably been growing more serious as the prevalence of outsourcing and off shoring has grown.

3. Key U.S. Statistical Agency Price Index Programs[4]

To better understand the measurement problems associated with outsourcing, a little background regarding the main U.S. price measurement programs of the BLS is helpful. These programs cover international (import and export) prices, domestic producer prices, and consumer prices.

Producers increasingly are sourcing intermediate inputs from both domestic and international producers. Hence there is growing interest in the development of a new input price index program that would span both domestically produced and foreign produced inputs.[5]

In considering the nature of the price measurement bias problems that are resulting from the growth of outsourcing and offshoring, and the challenges involved in developing an input price index for the United States, it is helpful to have some background on the U.S. Consumer Price Index (CPI) as well as the Producer Price Index (PPI) for domestic producer prices and the Import Price Index (MPI) for the prices of imported products. Previous related research on price index bias problems was carried out in a CPI context.

The U.S. *International Price Program (IPP)* produces and disseminates data on the foreign trade of the United States. The target universe consists of all goods and services sold by U.S. residents to foreign buyers for the export price indexes (XPI) and purchased from abroad by U.S. residents for the import price indexes (MPI). Ideally, the IPP should reflect the total breadth of U.S. trade in goods and services in the private sector. Goods shipped between establishments owned by the same company are also included. On the services side, however, there is progress, but the coverage is still far less than for goods.[6]

The import merchandise sampling frames are obtained from the U.S. Customs Service. The export merchandise sampling frames are obtained from the Canadian Customs Service for exports to Canada and from the Bureau of the Census for exports to the rest of the world.

A multistage design is used to select specific import and export items that can be priced over time. The first stage selects establishments independently within each broad product category (stratum). An establishment can be selected for more than one product category. The second stage selects detailed product categories within each establishment/product stratum pair.

During an initial visit to a selected establishment, a BLS field economist attempts to collect product items, item specifications, and initial prices for the selected items. Subsequent pricing is conducted by the BLS national office on a monthly basis for goods and on a quarterly basis for services. Designated respondents are sent a pricing form that contains previously supplied information about each product item to be priced, including detailed item descriptions

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[4] The material in this section draws heavily on chapters 14, 15 and 17 of the *BLS Handbook of Methods*, "International Price Indexes," available at http://www.bls.gov/opub/hom/pdf/homch15.pdf.

[5] See Alterman (2008), and Alterman, Siegel and Adonizio (2008).

[6] Jensen (2009) notes that services trade is growing and there is an increasing sense that technological change is making it easier and less expensive to provide services from a distance. Brown et al. (2009) have developed the 2009 National Organization Survey (NOS) designed to collect data on employment according to a set of exclusive and exhaustive business functions. They explain that the information collected would include data on outsourcing and off-shoringfor a representative sample of United States organizations.

and trade factors. The trade factors associated with each item include the country of origin/destination, any discount structure, the type of buyer or seller, and for imports when appropriate, the duty amount.

The *Producer Price Index (PPI)* measures average changes in prices received by *domestic* producers for their output. The output of virtually every industry in the mining and manufacturing sectors of the economy as well as from agriculture, fishing, forestry, utilities, and construction, and the output of the services and other sectors that produce intangible products is all conceptually within the PPI universe, though coverage is still sparse outside of the manufacturing sector.

In the case of the PPI, an individually designed sample is constructed for each industry. The first step in creating an industry sample is to compile a universe frame of establishments for the industry. The primary source for compiling an industry specific universe of establishments is the Unemployment Insurance (UI) administrative data because most employers are legally required to participate in the UI program.

Establishments are the appropriate units from which to collect production and employment data. However, in many cases, establishments are not the appropriate unit for the collection of producer price information. Thus the next step in constructing an industry sample consists of clustering establishments into price-forming units. Once a list of price-forming units in an industry has been compiled, the list may be stratified by variables appropriate for that industry. The criterion for identifying the sampling strata is whether price trends may be different for different values of a variable.

For each price-forming unit, the probability of selection for price collection is proportionate to size. Ideally, the proper measure of size would be the total revenue of the unit. However, employment is used as a proxy for size because employment information is more readily available. The BLS sample for the producers for each industry and output is updated every few years.

If an establishment agrees to participate in the PPI program, the BLS field economist proceeds to select those types of transactions that are to be priced through time from among all of the unit's revenue-producing activities. A probability sampling technique is used in this selection process. This procedure assigns to each category of items shipped, and to each category of other types of receipts, a probability of selection proportionate to the value of the category within the reporting unit. The categories selected are broken into additional detail in subsequent stages, until unique items or unique types of other receipts are identified. Even after a physically unique item has been selected, it is usually deemed necessary to disaggregate further. For example, if the same physical item is sold at more than one price, then the conditions that determine that price -- such as the size of the order, the type of customer, and so forth -- also must be selected on the basis of probability.[7] This method for identifying the transaction terms is said to ensure that the same type of transaction is priced over time and also to help minimize bias related to the specification of the terms of sale.[8]

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[7] Changes in transportation costs are reflected in industry price indexes only when the producing company delivers the product itself without hiring a third-party shipper.

[8] Because the PPI is meant to measure changes in net revenues received by producers, changes in excise taxes, which are revenues collected on behalf of the government, are not reflected in the index. However, changes in rebate

If the price indexes which are used to convert growth in nominal value added output into real value added output mostly miss input price declines associated with changes in input sourcing (including the sourcing changes that accompany outsourcing),[9] this can lead to biased estimates of economic growth and productivity as well as of inflation.

An extreme example may help convey the essence of the problem. Suppose that the price of each product remains fixed for the entire life of the product and all price adjustment occurs at the time of product replacements. Suppose that the product replacements involve no quality change. Consumers can observe the quality of each product, and they recognize that prices have been rising over time. However, a price index based only on price comparisons for identical items will remain constant over time in this example since prices only change along with product replacements.

The *Consumer Price Index (CPI)* provides a measure of the average change over time in the prices of consumer products. The set of all product items purchased by consumers is divided into 211 categories called item strata. Within each item stratum, one or more substrata, called entry-level items (ELIs), are defined.

In the spatial dimension, the urban portion of the United States is divided into 38 geographic areas. As already noted, the set of all product items purchased by consumers is divided into 211 categories called item strata, there are 8,018 (38 x 211) product item and area (i.e., item-area) combinations.

The CPI is calculated in two stages. The first stage is the calculation of basic indexes, which show the average price change for each of the 8,018 CPI product item-area combinations. Then, at the second stage, aggregate indexes are produced by averaging across subsets of the 8,018 CPI item-area combinations. The weights for the second stage are derived from expenditure aggregates compiled from Consumer Expenditure Survey (CE) data

The smallest geographic areas in which the first stage pricing is done for the CPI are called primary sampling units (PSUs). Within these areas, sales outlets are chosen where people shop. The selected outlets are matched to a sample of product items that consumers buy.

A BLS field representative visits each selected outlet. For each ELI assigned to the outlet for price collection, the field representative uses a multistage probability selection technique to select a specific item from among all the items the outlet sells that fall within the ELI definition. With the assistance of the outlet official designated to be the contact for the BLS for the CPI pricing exercise (referred to as the respondent for the outlet), the BLS field representative assigns probabilities of selection to each group. These probabilities are proportional to the sales of the items included in each group.

To enable the CPI to reflect changes in the marketplace, new product item and outlet samples are selected each year, on a rotating basis. Rotation of outlet and item samples by item category and geographic area, rather than by area alone, is believed to mitigate both outlet and product substitution bias problems.

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programs, low-interest financing plans, and other sales promotion techniques are reflected to the extent that these policies affect the net proceeds ultimately realized by the producer for a unit sale.

[9] Byrne, Kovak and Michaels (2009) note a similar problem with the IPP price indexes.

4. Constant Price Measures of Domestic Producer Purchases and Sales

In order to measure industry total factor productivity accurately, we require reliable information not only on the outputs produced and the labor input utilized by the industry but also on intermediate input utilized by the industry. In the United States, information on the nominal and real (i.e., constant dollar) purchases of intermediate inputs by industry comes from the system of input-output tables.

4.1 The U.S. input-output (I-O) tables

The benchmark nominal I-O make, use and requirements tables are briefly explained here. We then outline how these tables are converted to the corresponding real I-O tables, and discuss shortcomings of these tables..

The *make table* shows the production of commodities by industry. Each industry for the adopted industry classification gets its own row in a make table, and each product for the adopted product classification gets its own column. Across a row, all the commodities produced by an industry are identified, and the sum of these entries equals the output of the industry. Looking down a column, all the industries producing a specific commodity are given, and the sum of these entries equals the total output for that commodity.

The *use table* shows the uses of commodities by intermediate and final users. Each commodity gets a row in the use table, rather than a column as in the make table. And in a use table, part of the columns represent the different industries, some of which use some of the designated commodities as intermediate inputs, and the remaining columns are for the various types of final users for the products. The sum of the entries in a row is the output of a commodity. The columns show the products consumed by each industry as well as the compensation of employees, taxes on production, and imports less subsidies, and the gross operating surplus. The sum of the entries in a column is that industry's output.

In addition, there are four requirements tables: a direct requirements table and three total requirements tables. The *direct requirements table* shows the amount of a commodity that is required by each industry to produce a dollar of the industry's output. *Total requirements tables* show the relationship between final uses and gross output. The commodity-by-commodity total requirements table shows the production required, both directly and indirectly, of the commodity at the beginning of each row per dollar of delivery to final use of the commodity at the top of the column. The industry-by-commodity total requirements table shows the production required, both directly and indirectly, from the industry at the beginning of the row per dollar of delivery to final use of the commodity at the top of the column. And the industry-by-industry total requirements table shows the production required, both directly and indirectly, from the industry at the beginning of the row per dollar of delivery to final use of the industry at the top of the column.

Valuation concerns the decision to include or exclude taxes, subsidies and transport costs in the price of outputs and inputs. The 1993 System of National Accounts (SNA 1993)[10] distinguishes between valuations at basic prices, at producer's prices, and at purchaser's prices:

- *Basic price valuation* is intended to measure the amount retained by the producer; it excludes taxes payable and any transport charges invoiced separately, but includes subsidies receivable, as a consequence of production or sale.
- *Producer prices* include taxes on products, but exclude subsidies; rather than representing the amount actually retained by the producer (as for the basic price), producer price valuation reflects the amount at which a transaction was concluded or took place.
- *Purchaser's prices* are the amounts actually expensed by purchasers to take possession of products at specific places and times; thus, purchaser price valuation is especially relevant for purchasing decisions.

The SNA 1993 does not give much advice on how to construct real supply and use matrices, but countries that produce constant price input-output matrices, including the United States, use the following basic methodology:

- Construct gross output price indexes for the list of commodities that are distinguished by the statistical agency in its supply and use tables;
- Use these output based price indexes to deflate the cells in the corresponding commodity row along all of the industry columns of the matrix of gross output values produced during the accounting period in order to obtain a matrix of real gross outputs by commodity and industry (which is a real make matrix); and
- Again use the output based price indexes to deflate the cells in the corresponding commodity row along all of the industry columns of the matrix of intermediate input values purchased during the accounting period in order to obtain a matrix of real intermediate inputs by commodity and industry (which is a real use matrix).

The statistical agency then may find that total real supply by commodity does not equal the corresponding total real demand by commodity and various balancing exercises are sometimes used to achieve internal consistency within the I-O accounts between supply and demand.

A *transaction* is an economic flow between establishments, or from an establishment to a final user. Transactions are the principal building blocks for the construction of the I-O use table. Yet Horowitz and Planting (2006) explain that the estimation of transactions is often referred to as "the art of input-output" because of the paucity of data in many areas for measuring transactions. For example, whereas the use table purportedly shows the distribution of goods and services by their ultimate uses, many industries and final users report that they do not know how to supply information on the purchases of goods in producers' prices or on the associated costs of transportation and of trade markups. Thus, with the help of other data, officials of the U.S. Bureau of Economic Analysis (BEA) *estimate* the cost of transporting the goods and the costs associated with wholesaling or retailing these goods, and then they estimate the producer values.

[10] See Eurostat et al. (1993).

In order to measure industry total factor productivity accurately, reliable information is needed not only for the outputs produced and the labor input utilized by the industry but also for intermediate input utilized by the industry. Unfortunately, much of this information is created with the aid of assumptions that are unlikely to hold, especially in periods when outsourcing and off-shoring or in-shoring are growing.[11]

Even the intersectoral value flows of materials are incomplete. Moreover, there are no surveys (to our knowledge) on the interindustry flows of business services or for the inter-industry flows of leased capital. Indeed, using the present national accounts conventions, leased capital resides in the sector of ownership which is generally the Finance sector. This presumably leads to a large overstatement of the capital input into Finance and a corresponding underestimate of capital services use into the sectors where the leased capital is, in fact, utilized for production.

4.2 Associated employment measurement issues

Ruggles and Ruggles (1970) warn that:

> "It is important that the employment data be developed using precisely the same classifications used for income originating by industry. If this is done, it is then possible to derive income per worker by industry, and to show how this changes in different industries over time."

Yet, based on economic census data, the compensation of the leased employees is included in the employee leasing industry, which is part of the professional and business services sector. The employee leasing services industry is composed primarily of temporary help agencies and professional employer organizations (PEOs). Client industries that use leased employee services consume these services as intermediate inputs. Hence, economic census based labor compensation for client industries does *not* include the leased employees working on their premises.

BLS strives to include the employment and payroll of leased employees in the client industries where they work and provide labor services. However, Houseman (2007) is concerned that the indirect techniques used for the benchmark I-O accounts to impute some components of employment services to manufacturing industries have led to an understatement the quantity of labor used in manufacturing and to an overstatement of labor utilization in non-manufacturing. Houseman also argues that, because of how BLS compiles the estimates, both domestic and foreign outsourcing have important implications for productivity measurement.

Dey, Houseman and Polivka (2006) constructed a panel dataset on employment by occupation and industry. They use these data to document the dramatic rise in the number of employment services workers assigned to manufacturing over the period of 1989 to 2000. They

[11] For example, Eldridge and Harper (2009) explain that, "BEA produces import matrices as supplementary tables to the annual input-output (I-O) accounts. For each commodity, the import-matrix table shows the value of imports of that same commodity used by each industry. Because such information is not available from most businesses, the estimates must be imputed from data available in the annual I-O accounts. The imputed-import values are based on the assumption that each industry uses imports of a commodity in the same proportion as imports-to-domestic supply of the same commodity."

find that, although officially measured employment in manufacturing declined by 4.1 percent from 1989 to 2000, after counting employment services workers assigned to manufacturing, the employment in that sector rose by an estimated 1.4 percent. They also find that, from 2000 to 2001, staffing agency workers bore a disproportionate share of employment reductions in manufacturing, but that outsourcing to staffing services expanded again from 2001 to 2004.

In addition to having important implications for labor utilization, outsourcing to staffing services significantly affects labor productivity measurement in manufacturing. Outsourcing can distort simple labor productivity measures, defined as manufacturing output divided by manufacturing employment, because labor supplied by the contract sector is not counted in the denominator of the labor productivity measures.

4.3 The U.S. integrated annual industry accounts (AIAs)

The benchmark I-O tables introduced in section 4.1 provide the foundation for the production of the integrated annual industry accounts: the AIAs. The AIAs are integrated statistically and conceptually with the estimates of final expenditures and industry estimates of gross output and value added, and, in this sense, are internally consistent. The time series of the AIAs are estimated within the framework of balanced make and use tables. Yuskavage, Strassner, and Medeiros (2008) write that: "The additional layers of internal consistency in the AIAs increase the overall reliability of the estimates of intermediate inputs by industry."

The detailed benchmark accounts are prepared every five years using the most recent economic census data. To obtain annual updates of the AIAs, the BEA must estimate the composition of industry outputs and inputs. Nominal value added by industry estimates are available annually for the compensation of employees, taxes on production, imports less subsidies, and the gross operating surplus. Annual survey data are available from the Census Bureau for updating industry gross output for all of the manufacturing industries and for most of the services industries, including the industries that provide outsourcing-related services. Annual national accounts data are also available for updating estimates of final expenditures and imports. *However, data are not available annually for updating estimates of purchased services by manufacturing industries and purchased materials used by non-manufacturing industries.*

BEA's procedures for annual updates rely partly on the assumption that the real (constant-price) use of intermediate inputs relative to the industry's real gross output has not changed from the prior year. This is sometimes referred to as a "constant industry technology" assumption. An industry's real intermediate inputs are thus initially updated based on changes in its real gross output. The nominal value of its intermediate inputs for the current year is further adjusted based on price changes for the detailed commodity inputs.

Yuskavage, Strassner, and Medeiros (2008) write that the availability of the AIA data allows integrated analysis of industry output, inputs, employment, final demand, and imports.[12] They argue that the AIAs are well-suited for studying important developments in the economy including outsourcing "because the rich industry-level data on production, employment, and

[12] Similarly, Strassner, Yuskavage and Lee (2009) write that data from the BEA Annual Industry Accounts can be used to identify not only the uses of imported goods (intermediate vs. final) but also the overall importance of imported products by measuring their value relative to the value of comparable domestically produced goods.

prices are tightly integrated with the national economic accounts data for final uses and imports." Other researchers have used the input-output structure of the economy and detailed data on imports to impute imported goods and services to user industries and consumers (e.g., Kurz and Lengermann, 2008). However, the "internal consistency" of economic accounts is not necessarily equivalent to the accuracy of economic accounts. Some critics argue that the internal consistency serves as a camouflage for potentially important errors in the official statistics portrait of the U.S. economy.[13]

4.4 Foreign involvement and other problems with the U.S. I-O tables

I-O tables are frequently used to calculate the impact of changes in final uses on domestic output, income, or employment of industries using the total requirements matrix. However, in accord with the recommended practices of the SNA 1993,[14] the I-O tables used to develop these multipliers do not distinguish commodity inputs from foreign versus domestic sources. Hence, to calculate the domestic portion of the multiplier, the industry inputs from foreign sources must be removed, and this removal is accomplished using an import matrix created by assuming that imports are used *in the same proportion across all industries and final uses*: an assumption that allows BEA officials to *estimate* imports used as a share of the total use of each product item.

Houseman (2009) explains that import growth from developing countries vastly outpaced import growth from advanced countries from 2000 to 2007, and in recent years the current dollar value of non-petroleum commodity imports from developing countries exceeded that from advanced countries. The increase from China was particularly dramatic. The growth of offshore outsourcing and offshoring has spurred a heated debate over its effects on the U.S. economy and workers. Unfortunately, however, data on the use of imports by industries and final uses are not collected in the United States.

When an outlet supplying a price quote disappears and is replaced by a new outlet, the new outlet price quote does not immediately replace the missing price quote. Price quotes are obtained from the new outlet for at least two periods, and then a price ratio using only new outlet prices is linked into the index at the end of the second period. Thus any absolute change in prices going from the old outlet to the new outlet is ignored. This is the procedural source of the outlet substitution bias problem.[15]

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[13] Feenstra and Bradford (2009) state it is highly desirable to move beyond this assumption to obtain a direct measure of imported materials by industry, and we agree with them. The recently published Export and Import Price Index Manual: Theory and Practice also recommends extending the input output tables in the System of National Accounts and in Producer Price Index programs to distinguish industry supplies by domestic deliveries and exports and industry intermediate input demands by domestic sources and imports; see chapters 15, 18 and 19 in the International Monetary Fund (2009).

[14] See Table 15.1 in Eurostat et al. (1993).

[15] Marshall Reinsdorf (1993) directed attention to this problem. Subsequent analyses revealed that substantial portions of the estimated biases that Reinsdorf (1993) attributed to outlet substitution were, in fact, due to an index formula problem that was subsequently corrected; Reinsdorf and Moulton (1994) argue that when the BLS moved to probability sampling of prices in 1978, the micro price quotations were aggregated together using an index number formula that generates an upward bias. Moulton (1993), Reinsdorf (1994a), (1994b), (1994c) and Armknecht, Moulton and Stewart (1994) found supporting results too. However, other sorts of outlet substitution bias have subsequently been recognized.

Off-shoring involves the substitution of imported intermediate inputs for domestic inputs, presumably motivated in most cases by price considerations. Houseman (2008, 2009) argues that the U.S. price index programs (the CPI, PPI and IPP) involve procedural rules (summarized in section 3) that result in these indexes missing the effects of price changes such as the declines that often accompany changes in sourcing for inputs. All else equal, a growth of outsourcing or off-shoring or both would mean more changes in sourcing. If cost savings and input price declines typically occur along with switches to outsourcing or off-shoring or any other sourcing changes that result in a change of the company that is providing an input product, these savings and price declines will typically be missed by the official measures of price change. All else equal, the consequence will be an underestimate of the growth of real (i.e., constant price) imported inputs and real output, and productivity growth in U.S. industries will tend to be overstated. These measurement problems are similar in nature to the outlet substitution bias problem for the CPI.

5. Two Bias Problems in the IPP

5.1 Outlet substitution bias problems in the IPP

The U.S. import and export price indexes are based on micro price-data collected from U.S. firms. In these data, as reported by others,[16] roughly 5 percent of products are replaced each month. Also, reported prices change infrequently in these data. The frequency of price change of the median product is only about 8 percent per month. This implies that roughly 45% of price series in these data have no price changes and more than 70 percent have 2 price changes or less.

An important reason for the introduction of the IPP at the BLS was to be able to adequately control for quality and composition and thereby measure pure price changes. The IPP has therefore taken great care in the way it defines a product. The definition of a product in the IPP data includes not only a unique product identifier such as a bar code, but also other "price determining characteristics" identified by the BLS such as the terms of the transaction, size of the shipment and often even the identity of the seller. A product, as the BLS operationally uses the term, is therefore often a contract between a particular buyer and seller. A new product is not necessarily totally new to the world but rather new to a particular buyer-seller interaction.

From the perspective of controlling for quality change, it is probably desirable to define a product sufficiently narrowly that products with any observable differences in characteristics are viewed as entirely different products. However, for import and export prices, this approach would lead to difficulties in repricing some types of products since the products imported by a firm are found to differ slightly from one shipment to the next. To deal with this problem, the IPP takes a more pragmatic approach. In cases where there has been a substantial change in quality, the IPP discontinues the former item and initiates a new item with a new description. The product is also replaced if it is not possible to quantify the magnitude of the quality change, or if it is discontinued. To avoid sacrificing repricability, however, the IPP may deem some product characteristics to be non-price determining.

Problems with capturing price drops due to substitution in the Consumer Price Index (CPI) were recognized long ago. Diewert (1998) distinguishes and provides estimates of the

[16] See Gopinath and Rigobon (2008).

likely magnitude of three sorts of CPI substitution bias problems. (See appendix B for further details.) What Diewert refers to as the elementary substitution bias arises because of consumer substitution across outlets for commodities defined narrowly in terms of both the product attributes and the sales outlets. Commodity substitution has to do with consumer substitution among products. Finally, outlet substitution involves shifts in the outlets where consumers are buying. However, the potential counterpart problems with the Producer Price Index (PPI) and the Import Price Index (MPI) have been neglected.

5.2 Product replacement bias problems in the IPP

Emi Nakamura and Jón Steinsson (2009c) (NS hereafter) use IPP micro data on import and export prices over the period 1994-2007 to estimate the quantitative importance of product replacement bias.[17] More specifically, they use three sets of data. First, they use the microdata underlying the U.S. import and export price indexes. Second, they use aggregate U.S. import and export price indexes produced by the BEA. Third, they use exchange rate data from the Federal Reserve Board and the International Monetary Fund (IMF).

NS explain that if price adjustments disproportionately occur at the time of product replacements, with current index number practice, many price adjustments are missed. Prices change infrequently in the micro data that are used in compiling the MPI and XPI. According to NS, this apparent price stability reflects the reality that, in constructing price indexes, price adjustments that occur at the time of product replacements tend to be dropped.

NS explain that the IPP data are collected using voluntary surveys filled out by a designated "reporter" at each firm. To initiate a product into the dataset, IPP collects a detailed item description and a particular set of transaction terms. Item descriptions include the physical characteristics and specifications of an item, while transaction terms include the number or type of units priced, the country of destination or origin, the port of exit or entry, the discount structure, and in some cases the duty applied to the product.

After the product is initiated, price information is collected using a repricing form. The repricing forms include pre-filled information collected during the initialization process, such as the characteristics of the product, the terms of the transaction, and the discount structure. The repricing form first asks whether the price has changed relative to the previous month and then asks the respondent to report a new price if the price did change. One concern that NS raise about this procedure is that it may introduce a bias toward firms reporting no price change.

Of the total number of product-months in the database, NS find that reported prices are not available in about 40 percent of cases. A large fraction of product substitutions occur because one product is discontinued, to be replaced by a new product. If prices are renegotiated when firms start importing or exporting a product, then these prices will be reset, whereas the prices of many continuing products are rigid for a number of periods. NS report that about 60 percent of

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[17] The IPP is charged with collecting both interfirm and intrafirm prices for international trade. Because of difficulties in interpreting intrafirm transactions, NS exclude intrafirm prices in their baseline analysis.

the substitutions in the BLS data arise because the product that a particular firm is importing or exporting actually changes.[18]

For most products, however, it is costly and difficult to accurately measure quality change. Thus, a large fraction of product replacements are "linked-into" the index; so that the price comparison between the first observation of the new product and the last observation of the old product is dropped when changes in the index are calculated. The implicit assumption embodied in this linking practice for dealing with new products into the price index is that the frequency and size of price changes at the time of product replacements are the same on average as the frequency and size of price changes for continuing products. NS argue that this is a poor assumption since firms must set new prices for newly introduced products, while continuing products have a low probability of price change. If this perspective is correct, then conventional matched model price indexes will tend to underestimate the responsiveness of prices to aggregate variables since they disproportionately drop price change observations.

NS note that one way to view matched model price indexes is as implicitly imputing a price change for newly introduced products that is equal to the average change in the price of all continuing products. In contrast, their research indicates that the effective price change for newly introduced products has the same distribution as the effective price change of all continuing products that change their price in that period l. This implies that the change in the effective price of newly introduced products is much larger on average than the average price change of all continuing products.

NS refer to the resulting bias as "product replacement bias." They empirically quantify the magnitude of product replacement bias using estimates of price rigidity and the frequency of product replacements for U.S. import and export price data. [19] (Note that the bias problem they consider is *not* the outlet substitution bias problem in the literature on the CPI, since NS are assessing the impact on exchange rate pass through.).

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[18] NS explain that it is difficult to estimate the fraction of substitutions that involve a version change or upgrade. The dataset contains a flag indicating whether a product substitution is due to such a version change or upgrade. However, there are at least two reasons why this flag is unreliable. First, for most of the time period we study, to qualify as a version change or upgrade, the replacement product must fall into the same HS10 category. Since these categories are extremely disaggregated, it often happens that the replacement product falls in a different HS10 code. For example, male cows and female cows are different HS10, as are VHS players and DVD players. Second, NS report that BLS economists have indicated that many product discontinuations are followed by reinitiations of similar products by a BLS field representative.

[19] Monetary economists are especially worried about price rigidity because of its theoretical and empirical link to monetary neutrality. Nakamura and Steinsson (2009a) explain that: "Empirical evidence suggests that as much as 1/3 of the U.S. business cycle is due to nominal shocks." The treatment of intermediate goods is potentially very important in this literature too. Nakamura and Steinsson calibrate a multi-sector menu cost model using new evidence on the cross-sectional distribution of the frequency and size of price changes in the U.S. economy. They augment the model to incorporate intermediate inputs. They then show that the introduction of heterogeneity in the frequency of price change triples the degree of monetary non-neutrality generated by the model. They show furthermore that the introduction of intermediate inputs raises the degree of monetary non-neutrality by another factor of three, without adversely aecting the model's ability to match the large average size of price changes. Nakamura and Steinsson (2009a) conclude: "Our multi-sector menu cost model with intermediate inputs generates variation in real output in response to calibrated aggregate nominal shocks that can account for roughly 23% of the U.S. business cycle." For more empirical and theoretial evidence on price rigidity, see also Nakamura and Steinsson (2009b) (2009c) and E. Nakamura (2008).

6. Can the Bias in Input Price Indexes Due to Outsourcing Be Measured?

In the previous sections, we have discussed a number of economic measurement problems believed to result from, or that hamper proper assessment of, the growth of outsourcing and offshoring. Here and in appendix A we focus on just one of these problems: one for which we derive expressions for the resulting price index bias problem under alternative circumstances. The bias in input price indexes that results from a firm that switches from a high cost supplier to a lower cost supplier of an input can be measured in principle but it will not be easy to accomplish this task in practice.[20] We will first consider the case of domestic outsourcing and then at the end of this section, will note the modifications to the analysis that are necessary to deal with the case of offshore outsourcing.[21]

In this section, we will consider a very simple model where there are four establishments or firms, or more generally, four sectors in the domestic economy that are either producing or using a particular homogeneous commodity.[22] Two of the sectors are supplying the commodity to the other two sectors. The activities of the four sectors with respect to the homogeneous commodity can be described as follows:

- Sector 1 is a domestic high cost producer of the commodity and it sells the target output to sector 3 in periods 0 and 1;
- Sector 2 is a domestic low cost producer of the commodity and it sells the target output to sector 4 in both periods but it also sells this output to sector 3 in period 1;
- Sector 3 is a domestic sector that uses the output of the high cost sector in period 0 but in period 1, then switches some or all of its purchases of the homogeneous commodity to the low cost sector.[23] Thus sector 3 is the (domestic) outsourcing sector.
- Sector 4 is a domestic sector that uses the output of the low cost sector in both periods and does not purchase any high cost outputs from sector 2, the high cost sector.

The value flows between the sectors are shown in Table 1. The notation can be explained as follows: q_{13}^t denotes the deliveries of the homogeneous commodity from sector 1 to sector 3 in period t and p_{13}^t is the corresponding (unit value) price for t = 0,1; q_{24}^t denotes the deliveries of

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[20] There are many documented examples of narrowly defined input products being available from different producers for different prices. For example, Byrne, Kovak and Michaels (2009) report that, "after adjusting for changes in product characteristics, the average annual price decline in processed wafers was roughly 12.5 percent during the last five years." They also find that shifts in the location of production to lower-cost countries can contribute an additional price decline of up to 0.8 percent per year." And Klier and Ruberstein (2009) report that: "The mass-produced aluminum wheel is a commodity that is sourced by carmakers on the basis of price."

[21] Kletzer (2009) explains that, "research on offshore outsourcing has proceeded without much of a link to the domestic outsourcing literature.... Yet the domestic outsourcing literature has implications for offshore outsourcing research."

[22] In appendix A, we will extend the analysis in this section to the case where we are dealing with the simultaneous outsourcing of N commodities instead of just a single commodity.

[23] Initially, we will assume that Sector 1 continues to deliver output to Sector 3 in period 1. At the end of this section, we will consider how to deal with the case where Sector 1 shuts down in period 1.

the homogeneous commodity from sector 2 to sector 4 in period t and p_{24}^t is the corresponding (unit value) price for t = 0,1 and q_{23}^1 denotes the deliveries of the homogeneous commodity from sector 2 to sector 3 in period 1 and p_{23}^1 is the corresponding (unit value) price for period 1.[24] For each sector, output value flows have a positive sign and input purchases have a negative sign.

Table 1. Value Flows between the Four Sectors

Output flows		Input flows	
Sector 1	**Sector 2**	**Sector 3**	**Sector 4**
Period 0 Value Flows			
$p_{13}^0 q_{13}^0$	$p_{24}^0 q_{24}^0$	$- p_{13}^0 q_{13}^0$	$- p_{24}^0 q_{24}^0$
Period 1 Value Flows			
$p_{31}^1 q_{13}^1$	$p_{23}^1 q_{23}^1 + p_{24}^1 q_{24}^1]$	$- p_{31}^1 q_{13}^1 - p_{2}^1 q_{23}^1$	$- p_{24}^1 q_{24}^1$

Since sector 1 is a high cost supplier of the commodity and sector 2 is a low cost supplier, we assume that the following inequalities hold:

(1) $p_{13}^0 > p_{24}^0 > 0$; $p_{13}^1 > p_{24}^1 > 0$; $p_{13}^1 > p_{23}^1 > 0$.

Looking at the sectoral flows exhibited in Table 1, it can be seen that the *"true" output price index*, $P_T^{(1)}$, for Sector 1 is the ratio of the sector 1 selling price in period 1, p_{13}^1, to the selling price in period 0, p_{13}^0. Similarly, it is easy to see that the *"true" input price index*, $P_T^{(4)}$, for sector 4 is the ratio of the sector 4 purchase price in period 1, p_{24}^1, to the corresponding purchase price in period 0, p_{24}^0; i.e., we have:[25]

(2) $P_T^{(1)} \equiv p_{13}^1/p_{13}^0$; $P_T^{(4)} \equiv p_{24}^1/p_{24}^0$.

Determining the true output price index for sector 2 and the true input price index for sector 3 is more complex since there are two transactions in each of these sectors in period 1 at different prices and thus we do not have a unique period 1 price for these sectors. However, since the commodity being traded across sectors is assumed to be homogeneous, we follow the methodological advice given in the *Producer Price Index Manual*[26] and assume that unit value

[24] Normally we would expect p_{23}^1 to be close to p_{24}^1 but the present setup allows for possible price discrimination on the part of sector 2.

[25] We assume that the corresponding true quantity index is obtained by deflating the value ratio by the true price index. Thus $Q_T^{(1)} \equiv [p_{13}^1 q_{13}^1/p_{13}^0 q_{13}^0]/P_T^{(1)} = q_{13}^1/q_{13}^0$ and $Q_T^{(4)} \equiv [p_{24}^1 q_{24}^1/p_{24}^0 q_{24}^0]/P_T^{(4)} = q_{24}^1/q_{24}^0$.

[26] See the IMF et al. (2004; 509-510), Reinsdorf (1993) and Diewert (1995). The idea that a unit value for homogeneous items is the appropriate price to use in a bilateral index number formula can be traced back to Walsh (1901; 96) (1921; 88) and Davies (1924) (1932).

prices for the commodity are the appropriate prices to insert into an index number formula for sectors 2 and 3 in period 1. Thus we define the sector 2 and 3 *unit value prices*, u_2^1 and u_3^1, for period 1 as follows:

(3) $u_2^1 \equiv [p_{23}^1 q_{23}^1 + p_{24}^1 q_{24}^1]/[q_{23}^1 + q_{24}^1] = p_{23}^1 S_{23}^1 + p_{24}^1 S_{24}^1$;

(4) $u_3^1 \equiv [p_{13}^1 q_{13}^1 + p_{23}^1 q_{23}^1]/[q_{13}^1 + q_{23}^1] = p_{13}^1 S_{13}^1 + p_{23}^1 S_{23}^1$,

where S_{23}^1 is the share of sector 2's period 1 output that is delivered to sector 3, S_{24}^1 is the share of sector 2's period 1 output that is delivered to sector 4, S_{13}^1 is the share of sector 3's period 1 input that is purchased from sector 1 and S_{23}^1 is the share of sector 3's period 1 input that is purchased from sector 2. These shares are defined as follows:

(5) $S_{23}^1 \equiv q_{23}^1/[q_{23}^1 + q_{24}^1]$; $S_{24}^1 \equiv q_{24}^1/[q_{23}^1 + q_{24}^1]$; $S_{23}^1 + S_{24}^1 = 1$;

(6) $S_{13}^1 \equiv q_{13}^1/[q_{13}^1 + q_{23}^1]$; $S_{23}^1 \equiv q_{23}^1/[q_{13}^1 + q_{23}^1]$; $S_{13}^1 + S_{23}^1 = 1$.

Note that the sector 2 output shares defined by (5) and the sector 3 input shares defined by (6) are *physical shares*; not value shares.[27]

With the sector 2 period 1 unit value price u_2^1 defined by (3), the sector 2 *true output price index* can be defined as

(7) $P_T^{(2)} \equiv u_2^1/p_{24}^0 = (p_{23}^1/p_{24}^0)S_{23}^1 + (p_{24}^1/p_{24}^0)S_{24}^1$

where the last equation in (7) follows using (3). In a similar fashion, the sector 3 *true input price index* can be defined as

(8) $P_T^{(3)} \equiv u_3^1/p_{13}^0 = (p_{13}^1/p_{13}^0)S_{13}^1 + (p_{23}^1/p_{13}^0)S_{23}^1$.

In principle, there should be no problems for statistical agencies to compute the true price indexes defined by (2), (7) and (8) under the stated conditions.[28] However, there is likely to be a problem computing the true input price index for the outsourcing sector, sector 3. The problem is that since sector 3 has used a new source of supply in period 1 for which there is no matching source of supply in period 0, it is very likely that the statistical agency in charge of computing the Producer Price Index will use the following "matched model" *incorrect intermediate input price index* for sector 3:[29]

(9) $P_I^{(3)} \equiv p_{13}^1/p_{13}^0$.

The numerator in this incorrect index is the period 1 price from the high cost supplier, p_{13}^1, rather than the unit value price, u_3^1, which is an average price for sector 3 input purchases in period 1 over both high and low cost suppliers. Thus the incorrect sector 3 intermediate input price index will have an *upward bias* relative to the true index.

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[27] The difference between quantity shares and cost shares is likely to be empirically important when price levels of (quality adjusted) products differ, though the latter is often used. Moreover, with persistent differences in price levels between suppliers 1 and 2, growth in s, if measured by change in cost share, will understate quantity share growth (and estimates of the size of the index bias). We thank Susan Houseman for this observation.

[28] In practice, the stated conditions will probably not be met and there can be many practical problems associated with the computation of the true indexes.

[29] Recall the discussion in section 5.2 above on product replacement bias.

It is straightforward to develop a formula for this upward bias at the cost of introducing a bit more notation. Let i be the *rate of price inflation for deliveries from the high cost supplier* to sector 3 and let $0 < d < 1$ be the *discount factor* that reflects the proportional cost advantage of the low cost supplier relative to the high cost supplier in period 1 so that we have:

(10) $(1+i) = p_{13}^{1}/p_{13}^{0}$; $(1+i)(1-d) = p_{23}^{1}/p_{13}^{0}$.

From definition (8) for the sector 3 true input price index, we have:

(11) $P_T^{(3)} = (p_{13}^{1}/p_{13}^{0})S_{13}^{1} + (p_{23}^{1}/p_{13}^{0})S_{23}^{1}$

$= (1+i)S_{13}^{1} + (1+i)(1-d)S_{23}^{1}$ using (10)

$= (1+i) - (1+i)dS_{23}^{1}$ since $S_{13}^{1} + S_{23}^{1} = 1$

$= P_I^{(3)} - (1+i)dS_{23}^{1}$ using (9) and (10).

Define the *outsourcing bias* B in the incorrect index as the incorrect index less the true index. Using (11), we thus have:[30]

(12) $B \equiv P_I^{(3)} - P_T^{(3)} = (1+i)dS_{23}^{1} > 0.$

Therefore the outsourcing bias is the product of three factors:

- The rate of price inflation for the high cost supplier; i.e., $1+i = p_{13}^{1}/p_{13}^{0}$;
- The proportional cost advantage of the low cost supplier over the high cost supplier; i.e., $d = 1 - [(p_{23}^{1}/p_{13}^{0})/(p_{13}^{1}/p_{13}^{0})]$, and
- The share of deliveries to sector 3 in period 1 that are due to the new low cost supplier; i.e., $S_{23}^{1} = q_{23}^{1}/[q_{13}^{1} + q_{23}^{1}]$.

Thus if rough guesses for the cost advantage of the low cost supply price relative to the cost of the product from the higher cost suppliers being displaced can be made along with estimates of the input shares displaced, then a rough approximation to the bias in the intermediate input price index could be made using formula (12).[31]

The above analysis suggests the need for a new intermediate input survey that would collect price and quantity information from domestic producers about their intermediate input purchases. This new survey should be designed to reveal information about purchases from new suppliers so that appropriate unit values could be constructed using counterparts to formula (4) above.[32] This would not be an easy task!

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[30] The bias formula (12) is very similar to Diewert's (1998; 51) formula for outlet substitution bias in the CPI. See appendix B in this paper for a brief presentation of key related results from that 1998 paper.

[31] In appendix A, we show that the bias formula becomes more complex when we generalize the above one homogeneous commodity case to the case of many commodities. However, formula (12) is valuable as a very rough approximation to the bias.

[32] However, in order to construct the true indexes, we only need to know the appropriate unit value prices for each producer (irrespective of final destination) and the appropriate unit value prices for each intermediate input demander (irrespective of source). However, if the PPI program is integrated with the International Prices Program as well as with the construction of input output tables, then if it is desirable to have information on the exports produced and the imports demanded by each industrial sector, it will be necessary to construct unit value output prices for both exports and deliveries to domestic demanders and to construct unit value input prices for both

The extension of the above analysis to cover the case of a domestic sector outsourcing to a new foreign supplier is straightforward: simply reinterpret sector 2 as a foreign exporting sector (sector 1 could be a foreign or domestic supplier) and concentrate on the algebra surrounding sectors 3 and 4. All of the above algebra can be applied to sectors 3 and 4; only the interpretation of the variables associated with sector 2 (and possibly sector 1) is changed (from a domestic supplier to a foreign supplier). As before, there are no large conceptual issues with the input price index for sector 4, but again there will be problems constructing the input price index for sector 3. The statistical agency that has the task of constructing an import price index is very likely to compute the incorrect import price index for sector 3; i.e., when a domestic producer switches from one foreign supplier or a domestic supplier to an offshore low cost supplier, it is unlikely that the true input index for sector 3 will be computed.[33] In this case, the bias formula (12) is again operative.

The need for a new intermediate input price index survey is again highlighted, but now that imports are in the picture, the survey becomes more complex; i.e., for each sector in the domestic economy, *intermediate input purchases should be distinguished by their point of origin* so that it can be determined whether the purchases are to be classified as domestic intermediate input or imported input.

We conclude this section with some observations on what to do if sector 1 shuts down in period 1 so that p_{13}^1 and q_{13}^1 are not available. We will consider what could be done in the case where all four sectors are domestic sectors. The resulting true indexes for the sectors can be summarized as follows:

- It is not possible to compute the true output price index $P_T^{(1)}$ for sector 1;
- The true output price index for sector 2 remains the same as before; i.e., $P_T^{(2)}$ is still defined by (7);
- The true input price index for sector 3 can still be defined by (8) with $S_{13}^1 = 0$ and $S_{23}^1 = 1$, so in this case, $P_T^{(3)}$ simplifies to the (unmatched) price ratio p_{23}^1/p_{13}^0;
- There is no change in the true input price index for sector 4; i.e., $P_T^{(4)}$ is still defined by (2) so that $P_T^{(4)} = p_{24}^1/p_{24}^0$.

Thus except for the fact that an output price index for sector 1 can no longer be computed, it appears that all of the old algebra associated with the computation of true indexes for sectors 2-4 goes through if we simply set S_{13}^1 equal to 0. This is true as far as it goes but there are other complications:

imports and deliveries to the sector from domestic suppliers. If regional production accounts are required, then finer unit values for outputs and inputs by regional sector will be required: unit value prices for deliveries to each region and from each region will be required to implement these regional input output accounts. In the limit, unit value prices for each set of bilateral transactions between sectors will be required in order to avoid aggregation bias; see Diewert (2007b) or Chapter 19 in the Producer Price Index Manual for an example of how these bilateral accounts could be set up.

[33] If both sectors 1 and 2 are foreign sectors, then the intermediate input indexes for domestic sectors 3 and 4 are import price indexes; if sector 1 is a domestic sector and sector 2 is a foreign sector, then the input index for sector 3 is a hybrid intermediate and import price index whereas the sector 4 input index is a true import price index.

- The true input price index for sector 3 is the unmatched price ratio, $p_{23}{}^1/p_{13}{}^0$. Since the in this ratio prices come from different suppliers, the statistical agency is unlikely to use this index as a deflator for the sector 3 value ratio. Instead, the agency is likely to use the deflator associated with a closely related sector, namely sector 4, as the (incorrect) index for sector 3. The sector 4 price index is $p_{24}{}^1/p_{24}{}^0 \equiv P_I{}^{(3)}$, the ratio of selling prices for the commodity from the efficient supplier. With low inflation, this price ratio is likely to be close to one and hence will generally be larger than the mixed price ratio, $p_{23}{}^1/p_{13}{}^0 \equiv P_T{}^{(3)}$. Thus in general, we will have $P_I{}^{(3)} > P_T{}^{(3)}$[34] and the incorrect index will again have an upward bias. But the bias formula is no longer given by (12).[35]
- A true index cannot be computed for sector 1, but a statistical agency may want to compute a price index for the outputs produced by sectors 1 and 2 *combined* since this index can be computed. Since the two sectors are producing a homogeneous commodity by assumption, again the usual unit value pricing methodology can be used in order to form prices for the combined outputs of these two sectors. The appropriate unit value for the combined sectors in period 1 turns out to be $u_2{}^1$ defined by (3) above. Thus the appropriate period 0 unit value is $u^0 \equiv [p_{13}{}^0q_{13}{}^0 + p_{24}{}^0q_{24}{}^0]/[q_{13}{}^0 + q_{24}{}^0]$ and the resulting *combined sector true output price index* is $P_T{}^{(1+2)} \equiv u_2{}^1/u^0$. However, the statistical agency is not likely to compute this index. Instead, it is likely to use the price index for the most closely related sector (which is sector 2 in this case) as its index. Thus the *incorrect combined sector output price index* can be defined as $P_I{}^{(1+2)} \equiv u_2{}^1/p_{24}{}^0$. But under assumptions (1), $p_{24}{}^0$ turns out to be less than u^0, so $P_I{}^{(1+2)} > P_T{}^{(1+2)}$. Thus the incorrect index for the combined sectors also has an upward bias.

Some tentative conclusions emerge from the above analysis:

- Basic index number theory has not paid enough attention to the problems that arise when new firms enter and old firms exit and when production units outsource. Further research is required to explore how to deal with the complications associated with entry, exit and outsourcing.[36]
- It seems very likely that outsourcing and statistical agency standard operating procedures have led to upward biases in intermediate input and import price indexes. Upward biases in input price indexes lead to downward biases in the corresponding quantity indexes and have the effect of overstating total factor productivity improvements.
- Since the value of international trade as a proportion of GDP has increased steadily over time (until the recent great recession), it seems likely that outsourcing bias has also increased over time.

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[34] This inequality must hold under our assumptions (1) if $p_{23}{}^1 = p_{24}{}^1$; i.e., if the unit value prices for the low cost supplier are the same to sectors 3 and 4 in period 1 so that there is no price discrimination in period 1 by sector 2.

[35] The new bias formula will be $B \equiv P_I{}^{(3)} - P_T{}^{(3)} = (p_{24}{}^1/p_{24}{}^0) - (p_{23}{}^1/p_{13}{}^0)$.

[36] Thus we agree with Abraham and Spletzer (2009) that: "longitudinal data on the mix of jobs at individual enterprises could be useful for better understanding the dynamics of outsourcing and offshoring at the level of the individual firm."

7. Concluding Thoughts

7.1 Expanding the input-output accounts

The I-O tables serve as the framework for combining the available data for estimated GDP. The I-O tables are essential to empirical studies of how outsourcing and off-shoring and in-shoring are affecting the U.S. economy. Policy makers would like to know what factors account for current U.S. off-shoring. They would like to understand and be able to foresee and perhaps influence the major effects of off-shoring on U.S. workers and the economy. And they would like to know what additional data are needed to provide a more complete assessment of the effects and likely trends for outsourcing and for off-shoring.[37]

To allow for foreign engagement, the commodity classification that is used in the present supply and use tables must be expanded. A gross output that is being produced by a particular industry in a particular commodity category must be further distinguished as being supplied to the domestic market or as an export while an intermediate input that is being used by a particular industry in a particular commodity category would be further distinguished as being purchased from a domestic supplier or from a foreign supplier. Making the above changes to the main production accounts in SNA 1993 would not be a dramatic methodological leap since the present SNA already suggests the above treatment of intermediate inputs as a supplementary table.[38]

Also, one reason that input price indexes are needed that cover imported as well as domestically produced product items is for use by the U.S. Bureau of Economic Analysis (BEA) as deflators in compiling data on real intermediate input quantity inputs by industry, as part of the U.S. input-output tables. As of now, the same commodity price deflator is generally used to deflate the appropriate commodity value flows for each and every industry. As Diewert (2007c) has noted, this procedure is correct if each industry produces the same mix of micro commodities within each of the broad commodity classes and micro commodity prices are constant across industries: conditions unlikely to be satisfied for a national economy.

The same commodity price index that is used to deflate outputs across industries is also used to deflate intermediate inputs across industries. This multiple use of the same price index is justified if each industry faces the same micro commodity prices (both for outputs and intermediate inputs) and uses the same mix of micro commodities as intermediate inputs and in addition, each industry produces the same mix of micro commodities within each of the 1000 broad commodity classes in the commodity classification: more conditions that are unlikely to be satisfied. Unfortunately, there are strong reasons for the micro commodity output prices for a given commodity class to differ substantially from the corresponding micro commodity intermediate input prices. For example, transportation costs and taxes can cause differences of this sort.

Ideally, the make and use tables should be expanded so that we distinguish each transaction the delivery of goods and services, together with all the associated transportation and trade deals and tax specifics, by the purchaser and the seller. If we take the latter approach as the

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[37] See Norwood et al. (2006).

[38] See Table 15.5 in Eurostat et al. (1993). For a more detailed discussion of how exports and imports could be introduced into the production accounts, see Diewert (2007a) (2007b) and IMF et al. (2009).

ideal, the dimensionality of the supply and use tables would be expanded beyond what could conceivably be implemented in terms of needed data collection, given present survey data collection methods at least and business concerns about confidentiality.

However, this suggested approach could be partially implemented and the method serves as a useful benchmark for evaluating possible biases in existing methods. See Diewert (2005) (2007c) for a treatment of these problems in a closed economy context and Diewert (2007a), (2007b) for an open economy treatment.

7.2 New approaches to collecting data from businesses

Many firms have taken advantage of the low cost of computing and have detailed data on all their financial transactions (e.g., they have the value of each sale and the quantity sold by commodity). This opens up the possibility of the statistical agency's replacing or supplementing their surveys on, say, prices of outputs, by firms' electronic submission if the statistical agency of their computerized transaction histories for a certain number of periods. [39] This information would provide the industry or firm counterparts to the scanner data studies that have proved to be so useful in the context of the Consumer Price Index. This information would also lead to true microeconomic price and quantity indexes at the firm level and to accurate firm and industry productivity indexes.

If our purpose is to measure industry productivity, or to measure industry level product or labor demand impacts, then the answer is reasonably straightforward (but expensive). When calculating the constant dollar input-output matrices, each value cell for outputs and each value cell for inputs needs to be deflated by a price index that matches up with the value flows in that cell. At present, however, there simply are no adequate surveys on the interindustry flows of services. Even in manufacturing, where information on commodity flows is relatively complete thanks to explicit surveys of manufacturing industries, no information on the flow of purchased services is collected.

More attention needs to be given as well to the development of basic prices by industry and by commodity, i.e. we need accurate information on the exact location of indirect taxes (and commodity subsidies) by commodity and industry on both outputs and intermediate inputs.

Appendix A Outsourcing Bias when there are N Commodities Being Outsourced

The analysis in the main text that was associated with Table 1 dealt only with the case of a single homogeneous commodity. In theory, this analysis could be applied to every single outsourced commodity. However, in reality, statistical agencies do not construct "incorrect" indexes at the level of one commodity. Hence in this Appendix, we will define the "incorrect" indexes as aggregates over N commodities rather than over a single commodity. The over all message will remain the same but the details will of course be more complex.

In this more general setup, instead of assuming that sector 3 outsources only one commodity, we will assume that sector 3 *simultaneously out sources N homogeneous*

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[39] For more on new ways of collecting price data, see also Gudmundsdottir, Gudnason and Jonsdottir (2008) and Grimm, Moulton and Wasshausen (2002).

commodities; i.e., sector 3 switches some of its input needs from sector 1 (the high cost supplier) to sector 2 (the low cost supplier) for N commodities. Thus the flows in Table 1 are still applicable except that now each price and quantity is to be interpreted as a price and quantity vector and the old ordinary products of price and quantity are now to be interpreted as inner products of the corresponding price and quantity vectors. Thus the old value flow of supplies from sector 1 to sector 3 in period t, $p_{13}^tq_{13}^t$, is now replaced by $p_{13}^t\cdot q_{13}^t \equiv \sum_{n=1}^N p_{13n}^tq_{13n}^t$ for t = 0,1 where p_{13}^t is defined as the price vector $[p_{131}^t,p_{132}^t,...,p_{13N}^t]$ and where q_{13}^t is defined as the quantity vector $[q_{131}^t,q_{132}^t,...,q_{13N}^t]$ for t = 0,1. Similarly, the value flows from sector 2 to sector 4 in period t, $p_{24}^tq_{24}^t$, is now replaced by the inner product $p_{24}^t\cdot q_{24}^t \equiv \sum_{n=1}^N p_{24n}^tq_{24n}^t$ for t = 0,1 where p_{24}^t is defined as the price vector $[p_{241}^t,p_{242}^t,...,p_{24N}^t]$ and where q_{24}^t is defined as the quantity vector $[q_{241}^t,q_{242}^t,...,q_{24N}^t]$ for t = 0,1. Finally, the value flow from sector 2 to sector 3 in period 1, $p_{23}^1q_{23}^1$, is replaced by the inner product, $p_{23}^1\cdot q_{23}^1$.

Let p^t and q^t be generic price and quantity vectors pertaining to a sector for periods t = 0,1. Then the *Laspeyres and Paasche price indexes*, P_L and P_P, are defined as follows:

(A1) $P_L(p^0,p^1,q^0,q^1) \equiv p^1\cdot q^0/p^0\cdot q^0$; $P_P(p^0,p^1,q^0,q^1) \equiv p^1\cdot q^1/p^0\cdot q^1$.

The *Fisher* (1922) *ideal price index*, P_F, is defined as the geometric mean of the Laspeyres and Paasche price indexes:

(A2) $P_F(p^0,p^1,q^0,q^1) \equiv [P_L(p^0,p^1,q^0,q^1)P_P(p^0,p^1,q^0,q^1)]^{1/2}$.

The Fisher price index can be justified as a "best" index from both the view point of the economic approach to index number theory as well as from the axiomatic or test approach[40] and so we will use it as our preferred "true" index in what follows.

Looking at Table 1 in the main text with our new interpretation of the value flows, it can be seen that there are no outsourcing switching problems associated with the sector 1 and sector 4 value flows. Thus we can define the *true output price index for sector 1*, $P_T^{(1)}$, as the Fisher index $P_F(p_{13}^0,p_{13}^1,q_{13}^0,q_{13}^1)$ and the *true input price index for sector 4*, $P_T^{(4)}$, as the Fisher index $P_F(p_{24}^0,p_{24}^1,q_{24}^0,q_{24}^1)$. However, for sectors 2 and 3, it is necessary to define *unit value prices* for the N commodities in period 1 as follows:

(A3) $u_{2n}^1 \equiv [p_{23n}^1q_{23n}^1 + p_{24n}^1q_{24n}^1]/[q_{23n}^1 + q_{24n}^1] = p_{23n}^1S_{23n}^1 + p_{24n}^1S_{24n}^1$; n = 1,...,N ;

(A4) $u_{3n}^1 \equiv [p_{13n}^1q_{13n}^1 + p_{23n}^1q_{23n}^1]/[q_{13n}^1 + q_{23n}^1] = p_{13n}^1S_{13n}^1 + p_{23n}^1S_{23n}^1$; n = 1,...,N

where the *sector 2 and 3 (physical) quantity shares for commodity n in period 1* are defined as follows:

(A5) $S_{23n}^1 \equiv q_{23n}^1/[q_{23n}^1 + q_{24n}^1]$; $S_{24n}^1 \equiv q_{24n}^1/[q_{23n}^1 + q_{24n}^1]$; $S_{23n}^1 + S_{24n}^1 = 1$; n = 1,...,N;

(A6) $S_{13n}^1 \equiv q_{13n}^1/[q_{13n}^1 + q_{23n}^1]$; $S_{23n}^1 \equiv q_{23n}^1/[q_{13n}^1 + q_{23n}^1]$; $S_{13n}^1 + S_{23n}^1 = 1$; n = 1,...,N.

Let the vector of sector 2 unit value prices for period 1 be $u_2^1 \equiv [u_{21}^1,u_{22}^1,...,u_{2N}^1]$ where the u_{2n}^1 are defined by (A3) and let vector of sector 3 unit value prices for period 1 be $u_3^1 \equiv [u_{31}^1,u_{32}^1,...,u_{3N}^1]$ where the u_{3n}^1 are defined by (A4). The period 1 quantity vectors that correspond to these unit value vectors in period 1 are $q_{23}^1+q_{24}^1$ for sector 2 and $q_{13}^1+q_{23}^1$ for

[40] See Diewert (1976) (1992) and the *Producer Price Index Manual*.

sector 3. Thus our *true indexes* for sectors 2 and 3 are defined to be the following Fisher ideal price indexes:

$$\text{(A7)}\ P_T^{(2)} \equiv P_F(p_{24}^0,u_2^1,q_{24}^0,q_{23}^1+q_{24}^1)$$
$$= [P_L(p_{24}^0,u_2^1,q_{24}^0,q_{23}^1+q_{24}^1)P_P(p_{24}^0,u_2^1,q_{24}^0,q_{23}^1+q_{24}^1)]^{1/2};$$

$$\text{(A8)}\ P_T^{(3)} \equiv P_F(p_{13}^0,u_3^1,q_{13}^0,q_{13}^1+q_{23}^1)$$
$$= [P_L(p_{13}^0,u_3^1,q_{13}^0,q_{13}^1+q_{23}^1)P_P(p_{13}^0,u_3^1,q_{13}^0,q_{13}^1+q_{23}^1)]^{1/2}.$$

In principle, there should be no problem in principle for a statistical agency to compute the true output price index $P_T^{(2)}$ defined by (A7) since this index makes use of the sector specific unit values defined above by (A3).[41] However, there is likely to be a problem computing the true input price index, $P_T^{(3)}$ defined by (A8), for the outsourcing sector, sector 3. The problem is that as sector 3 has switched to a new supplier in period 1 for the N commodities under consideration, there will be no matching source for these supplies in period 0, and so it is very likely that the statistical agency in charge of computing the Producer Price Index for sector 3 will use the following "matched model" *incorrect intermediate input price index* for sector 3:

$$\text{(A9)}\ P_I^{(3)} \equiv [P_L(p_{13}^0,p_{13}^1,q_{13}^0,q_{13}^1)P_P(p_{13}^0,p_{13}^1,q_{13}^0,q_{13}^1)]^{1/2}.$$

Note that the incorrect index $P_I^{(3)}$ is the geometric mean of the Laspeyres and Paasche price indexes, $P_L(p_{13}^0,p_{13}^1,q_{13}^0,q_{13}^1)$ and $P_P(p_{13}^0,p_{13}^1,q_{13}^0,q_{13}^1)$, and these indexes use only the price and quantity data that pertains to the "traditional" supplier of the N commodities for both periods, which is sector 1. Since sector 1 is a high cost supplier, we can expect $P_I^{(3)}$ to be higher than the true index, $P_T^{(3)}$. In the following paragraphs, we will develop formulae that will enable us to determine the magnitude of this upward bias in the incorrect index.

It is a bit too messy to develop a bias formula for the difference $P_I^{(3)}$ less $P_T^{(3)}$ but it is fairly easy to develop bias formulae for the differences between the Laspeyres and Paasche components in each of these indexes. Thus we start our analysis by converting the high cost supplier price relatives, p_{13n}^1/p_{13n}^0, and the low cost supplier prices in period 1 relative to the corresponding high cost supplier prices in period 0, p_{23n}^1/p_{13n}^0, into *commodity specific inflation rates* as follows:

$$\text{(A10)}\ p_{13n}^1/p_{13n}^0 \equiv (1+i_n)\ ; \qquad n = 1,...,N\ ;$$

$$\text{(A11)}\ p_{23n}^1/p_{13n}^0 \equiv (1-d_n)(1+i_n); \qquad n = 1,...,N$$

where d_n is a *proportional discount factors* which gives the cost advantage of the low cost supplier for commodity n. We assume that these discount factors are positive so that we are assuming the following inequalities:

$$\text{(A12)}\ 0 < d_n < 1; \qquad n = 1,...,N.$$

We start our analysis by looking at the *Laspeyres component* $P_{TL}^{(3)}$ in the true input price index defined by (A8):

[41] Thus if the sector is an establishment, these unit values can in principle be calculated by the statistical agency if all of the sales of that establishment for the N commodities are recorded by the establishment in each period with a price and quantity breakdown for each sale of these commodities (and these data are made available to the statistical agency).

(A13) $P_{TL}^{(3)} \equiv P_L(p_{13}^0,u_3^1,q_{13}^0,q_{13}^1+q_{23}^1)$

$\equiv u_3^1 \cdot q_{13}^0/p_{13}^0 \cdot q_{13}^0$

$= \sum_{n=1}^N [p_{13n}^1 S_{13n}^1 + p_{23n}^1 S_{23n}^1] q_{13n}^0/p_{13}^0 \cdot q_{13}^0$ using definitions (A4)

$= \sum_{n=1}^N [(p_{13n}^1/p_{13n}^0) S_{13n}^1 + (p_{23n}^1/p_{13n}^0) S_{23n}^1] p_{13n}^0 q_{13n}^0/p_{13}^0 \cdot q_{13}^0$

$= \sum_{n=1}^N [(1+i_n) S_{13n}^1 + (1-d_n)(1+i_n) S_{23n}^1] p_{13n}^0 q_{13n}^0/p_{13}^0 \cdot q_{13}^0$ using (A10) and (A11)

$= \sum_{n=1}^N [(1+i_n) S_{13n}^1 + (1-d_n)(1+i_n) S_{23n}^1] s_{13n}^0$ using (A14) below

$= \sum_{n=1}^N (1+i_n) s_{13n}^0 - \sum_{n=1}^N d_n(1+i_n) S_{23n}^1 s_{13n}^0$ using (A6)

where the *period 0 expenditure shares on the N commodities by sector 3* are defined as follows:

(A14) $s_{13n}^0 \equiv p_{13n}^0 q_{13n}^0/p_{13}^0 \cdot q_{13}^0$; $n = 1,\ldots,N$.

It is straightforward to show that $\sum_{n=1}^N (1+i_n) s_{13n}^0$ is the *incorrect Laspeyres component*, $P_L(p_{13}^0,p_{13}^1,q_{13}^0,q_{13}^1)$, in the incorrect Fisher price index for sector 3 defined by (A9) above; i.e., we have:

(A15) $P_{IL}^{(3)} \equiv P_L(p_{13}^0,p_{13}^1,q_{13}^0,q_{13}^1) = \sum_{n=1}^N (1+i_n) s_{13n}^0$.

Thus if we define the *bias* B_L *in the incorrect Laspeyres index* as the difference between $P_{IL}^{(3)}$ and $P_{TL}^{(3)}$, using (A13) and (A15), we have the following expression for this bias:

(A16) $B_L \equiv P_{IL}^{(3)} - P_{TL}^{(3)} = \sum_{n=1}^N d_n(1+i_n) S_{23n}^1 s_{13n}^0 > 0$

where the inequality follows from the nonnegativity of the physical shares S_{23n}^1 (with at least one of these shares positive), the positivity of the base period expenditure shares s_{13n}^0 and the positivity of the discount factors d_n. It can be seen that the bias formula (A16) has the same general structure as the bias formula (12) in the main text except that now, the base period expenditure shares s_{13n}^0 of the outsourcing sector on the N commodities that were outsourced in period 1 enter into the formula.

We now need to repeat the above analysis for the *Paasche component of the true index* $P_T^{(3)}$ defined by (A8) and the *Paasche component of the incorrect index* $P_I^{(3)}$ defined by (A9). Define these Paasche components as follows:

(A17) $P_{TP}^{(3)} \equiv P_P(p_{13}^0,u_3^1,q_{13}^0,q_{13}^1+q_{23}^1) \equiv u_3^1 \cdot (q_{13}^1+q_{23}^1)/p_{13}^0 \cdot (q_{13}^1+q_{23}^1)$;

(A18) $P_{IP}^{(3)} \equiv P_P(p_{13}^0,p_{13}^1,q_{13}^0,q_{13}^1) \equiv p_{13}^1 \cdot q_{13}^1/p_{13}^0 \cdot q_{13}^1$.

In place of the base period expenditure shares s_{13n}^0, for our Paasche analysis, we will require two sets of expenditure weights that use the prices of period 0 but quantities that pertain to period 1. Thus define the following two sets of *hybrid expenditure shares*:

(A19) $s_n^{01} \equiv p_{13n}^0 q_{13n}^1/p_{13}^0 \cdot q_{13}^1$; $n = 1,\ldots,N$;

(A20) $s_n^{01*} \equiv p_{13n}^0 (q_{13n}^1+q_{23n}^1)/p_{13}^0 \cdot (q_{13}^1+q_{23}^1)$; $n = 1,\ldots,N$.

The expenditure shares s_n^{01} use the base period prices for sector 3, p_{13}^0, and the deliveries of the high cost sector to sector 3 in period 1, q_{13}^1, whereas the expenditure shares s_n^{01*} use the base period prices for sector 3, p_{13}^0, as the price vector and the sum of all deliveries to sector 3 in period 1, $q_{13}^1+q_{23}^1$, as the quantity vector.

We start our analysis of the bias in the Paasche components of the true and incorrect Fisher indexes by looking at the *Paasche component* $P_{TP}^{(3)}$ of the true input price index defined by (A8). Using definition (A17), we have

$$\text{(A21)}\ P_{TP}^{(3)} \equiv u_3^1\cdot(q_{13}^1+q_{23}^1)/p_{13}^0\cdot(q_{13}^1+q_{23}^1)$$
$$= \sum_{n=1}^N [p_{13n}^1 S_{13n}^1 + p_{23n}^1 S_{23n}^1][q_{13n}^1 + q_{23n}^1]/p_{13}^0\cdot[q_{13}^1+q_{23}^1] \quad \text{using (A4)}$$
$$= \sum_{n=1}^N [(p_{13n}^1/p_{13n}^0)S_{13n}^1 + (p_{23n}^1/p_{13n}^0)S_{23n}^1]s_n^{01*} \quad \text{using (A20)}$$
$$= \sum_{n=1}^N [(1+i_n)S_{13n}^1 + (1-d_n)(1+i_n)S_{23n}^1]\, s_n^{01*} \quad \text{using (A10) and (A11)}$$
$$= \sum_{n=1}^N (1+i_n)s_n^{01*} - \sum_{n=1}^N d_n(1+i_n)S_{23n}^1 s_n^{01*} \quad \text{using (A6).}$$

In a similar fashion, we look at the *Paasche component* $P_{IP}^{(3)}$ of the incorrect input price index defined by (A9). Using definition (A18), we have:

$$\text{(A22)}\ P_{IP}^{(3)} \equiv p_{13}^1\cdot q_{13}^1/p_{13}^0\cdot q_{13}^1$$
$$= \sum_{n=1}^N (p_{13n}^1/p_{13n}^0)p_{13n}^0 q_{13n}^1/p_{13}^0\cdot q_{13}^1$$
$$= \sum_{n=1}^N (1+i_n)s_n^{01} \quad \text{using (A10) and (A19).}$$

Define the *bias* B_P *in the incorrect Paasche index* as the difference between $P_{IP}^{(3)}$ and $P_{TP}^{(3)}$. Using (A21) and (A22), we have the following expression for this bias:

$$\text{(A23)}\ B_P \equiv P_{IP}^{(3)} - P_{TP}^{(3)}$$
$$= \sum_{n=1}^N (1+i_n)s_n^{01} - \sum_{n=1}^N (1+i_n)s_n^{01*} + \sum_{n=1}^N d_n(1+i_n)S_{23n}^1 s_{13n}^{01*}$$
$$= \sum_{n=1}^N (1+i_n)[s_n^{01} - s_n^{01*}] + \sum_{n=1}^N d_n(1+i_n)S_{23n}^1 s_{13n}^{01*}.$$

Under normal conditions, the first term in the last line of (A23) will be close to zero[42] and thus the second term, $\sum_{n=1}^N d_n(1+i_n)S_{23n}^1 s_{13n}^{01*}$, will dominate. Since this second term is positive under our assumptions, the Paasche component of the bias, B_P, will usually be positive. Note that this second term has the same general form as the Laspeyres bias component B_L defined above by (A16).

If we approximate the true Fisher index $P_T^{(3)}$ defined by (A8) by the arithmetic mean of its Laspeyres and Paasche components and we approximate the incorrect Fisher index $P_I^{(3)}$ defined by (A9) by the arithmetic mean of its Laspeyres and Paasche components, then the bias expressions (A16) and (A23) can be used to form an overall estimate of the bias in the incorrect Fisher index.

The above techniques can also be used to develop bias formulae for *elementary indexes*; i.e., price indexes that use only price information for the two periods under consideration.[43] We will finish this Appendix by developing bias formulae for the Carli and Jevons indexes applied to sector 3.

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[42] If all of the commodity specific inflation rates for the high cost producer are equal (i.e., the i_n are all equal), then it can be seen that the first term on the right hand side of (A23) will vanish since the two sets of shares sum to one. This term will also be zero if the correlation between the vector of commodity specific inflation rates i_n and the vector of differences in the shares is zero.

[43] For general discussions on elementary indexes, see Diewert (1995) and the IMF et al. (2004; 508-524).

The *true Carli price index* for sector 3, $P_{TC}^{(3)}$, is simply the arithmetic average of the ratio of the unit values for this sector; i.e., we have:

$$\begin{aligned}
\text{(A24)}\ P_{TC}^{(3)} &\equiv \textstyle\sum_{n=1}^{N} (1/N)(u_{3n}^{1}/p_{13n}^{0}) \\
&= \textstyle\sum_{n=1}^{N} (1/N)(p_{13n}^{1}S_{13n}^{1} + p_{23n}^{1}S_{23n}^{1})/p_{13n}^{0} && \text{using definitions (A4)} \\
&= \textstyle\sum_{n=1}^{N} (1/N)[(p_{13n}^{1}/p_{13n}^{0})S_{13n}^{1} + (p_{23n}^{1}/p_{13n}^{0})S_{23n}^{1}] \\
&= \textstyle\sum_{n=1}^{N} (1/N)[(1+i_n)S_{13n}^{1} + (1-d_n)(1+i_n)S_{23n}^{1}] && \text{using (A10) and (A11)} \\
&= \textstyle\sum_{n=1}^{N} (1/N)(1+i_n) - \sum_{n=1}^{N} d_n(1+i_n)S_{23n}^{1} && \text{using (A6)} \\
&= P_{IC}^{(3)} - \textstyle\sum_{n=1}^{N} d_n(1+i_n)S_{23n}^{1}
\end{aligned}$$

where the *incorrect Carli index* is defined as

$$\text{(A24)}\ P_{IC}^{(3)} \equiv \textstyle\sum_{n=1}^{N} (1/N)(p_{3n}^{1}/p_{13n}^{0}) = \sum_{n=1}^{N} (1/N)(1+i_n).$$

Thus the incorrect Carli index is defined as the arithmetic mean of the matched prices for sector 3; i.e., p_{3n}^{1} is used in place of the theoretically preferred unit value prices for period 1, u_{3n}^{1}. Define the *Carli index bias*, B_C, for sector 3 as the incorrect Carli index less the correct Carli index. Using (A24), we have:

$$\text{(A25)}\ B_C \equiv P_{IC}^{(3)} - P_{TC}^{(3)} = \textstyle\sum_{n=1}^{N} d_n(1+i_n) \sum_{n=1}^{N} d_n(1+i_n)S_{23n}^{1} > 0$$

where the inequality follows from the positivity of the d_n and $1+i_n$ and the nonnegativity of the quantity shares S_{23n}^{1} (with at least one such share being positive). Thus the incorrect Carli index will have an upward bias.

The *true Jevons price index* for sector 3, $P_{TC}^{(3)}$, is simply the geometric mean of the ratio of the unit values for this sector; i.e., we have:

$$\begin{aligned}
\text{(A26)}\ P_{TJ}^{(3)} &\equiv \textstyle\prod_{n=1}^{N} [u_{3n}^{1}/p_{13n}^{0}]^{1/N} \\
&= \textstyle\prod_{n=1}^{N} [(p_{13n}^{1}S_{13n}^{1} + p_{23n}^{1}S_{23n}^{1})/p_{13n}^{0}]^{1/N} && \text{using definitions (A4)} \\
&= \textstyle\prod_{n=1}^{N} [(1+i_n)S_{13n}^{1} + (1-d_n)(1+i_n)S_{23n}^{1})]^{1/N} && \text{using (A10) and (A11)} \\
&= \textstyle\prod_{n=1}^{N} [(1+i_n) - d_n(1+i_n)S_{23n}^{1})]^{1/N} && \text{using (A6)} \\
&= [\textstyle\prod_{n=1}^{N} (1+i_n)^{1/N}][\prod_{n=1}^{N} (1 - d_nS_{23n}^{1})^{1/N}] \\
&= P_{IJ}^{(3)} \textstyle\prod_{n=1}^{N} (1 - d_nS_{23n}^{1})^{1/N}
\end{aligned}$$

where the *incorrect Jevons index* is defined as

$$\text{(A27)}\ P_{IJ}^{(3)} \equiv \textstyle\prod_{n=1}^{N} [p_{3n}^{1}/p_{13n}^{0}]^{1/N} = \prod_{n=1}^{N} (1+i_n)^{1/N}.$$

Thus the incorrect Jevons index is defined as the geometric mean of the matched prices for sector 3; i.e., p_{3n}^{1} is used in place of the theoretically preferred unit value prices for period 1, u_{3n}^{1}. Define the *Jevons index bias relative bias*, B_J, for sector 3 as the incorrect Jevons index divided by the correct Jevons index. Using (A26), we have:

$$\text{(A28)}\ B_J \equiv P_{IJ}^{(3)}/P_{TJ}^{(3)} = P_{IJ}^{(3)}/\{P_{IJ}^{(3)} \textstyle\prod_{n=1}^{N} (1 - d_nS_{23n}^{1})^{1/N}\} = 1/\prod_{n=1}^{N} (1 - d_nS_{23n}^{1})^{1/N}\} > 1$$

where the inequality follows from the inequalities $0 < d_n < 1$ and the nonnegativity of the quantity shares S_{23n}^1 (with at least one such share being positive). Thus the incorrect Jevons index will have an upward bias.

Appendix B Diewert's Approximations for Recognized CPI Bias Problems[44]

This appendix first takes up three kinds of substitution: "at the elementary index level," at the commodity level, and between outlets. Biases associated with the introduction of new goods are then considered.

An elementary good is a narrowly defined commodity purchased at a specific retail outlet. At this level of definition, survey information about consumer expenditures is not available. Households may purchase a commodity, defined more broadly as in the consumer expenditure surveys and in the input-output tables, at a variety of prices at different outlets. The price heterogeneity at the elementary level of aggregation must somehow be summarized as a single price that can be inserted into an index number formula. The appropriate price that should be inserted into an index number formula at the lowest level of aggregation appears to be an "outlet unit value," defined as the total value of the commodity sold during the time period at a given sample of outlets divided by the corresponding quantity sold at all of the sampled outlets.[45]

Elementary substitution bias B_E can be defined as the difference between the fixed base Laspeyres index P_L and the corresponding Fisher index P_F, where the prices in these indexes refer to some homogeneous component of the CPI. The Appendix shows that this bias will be approximately equal to one-half the Laspeyres price index PL times the variance of the inflation-adjusted percentage changes in prices among the goods examined:

(B1) $$B_E \equiv P_L - P_F \cong (1/2)(1+i)\mathrm{Var}(\varepsilon),$$

where i is the inflation rate in the CPI component as measured by its Laspeyres price index; that is, $1+i = P_E$. For the purposes of illustration, assume that the variance of the percentage change in prices is .005. Then, according to the formula, inflation rates at the present level of about 2 percent will imply that the Laspeyres index is upwardly biased by .00255, or .255 percentage points.

In the case of *commodity substitution bias*, this calculation can be repeated, except that, in this case, the aggregation is happening across different commodity prices instead of prices for the same commodity across different outlets. It is difficult to say a priori whether the variability of outlet prices for the same commodity is greater or less than the variability of prices across commodities. But if we stick with a variance estimate of .005 and an inflation estimate of 2 percent, then commodity substitution bias would be another .255 percentage points. These two effects taken together would represent an upward bias of .5 percentage points.

Now let us return to the subject of *outlet substitution bias*, which was assumed away by the earlier formulation. Suppose that discount outlets move into a market area and capture market share from traditional high cost retailers. If differences in the services provided by

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[44] This subsection draws heavily on Diewert (1998).

[45] Diewert (1995; 20-24) discusses this approach.

discount and traditional retailers are neglected (a controversial assumption), then a reasonable concept of the "true" price index is the average price (or unit value) paid by consumers over all outlets; see Reinsdorf (1993), Hill (1993, 399), and Diewert (1995; 28). In this case, the relationship between the Laspeyres index and the true price index can be defined as:

(B2) $P_T \equiv (1-s)(1+i) + s(1+i)(1-d)$,

where (1 + i) = PL is the Laspeyres price index for the traditional retailers in the current period, s is the market share captured by low cost retailers in the current period and d is the percentage discount of the low cost retailer over traditional retailers. This formula implicitly assumes that the discount is constant in the two periods and the period-to-period trend in discount retail prices is the same as the traditional retailer's trend. Essentially, this formula says that to take the discount stores into account, one must weight the existing Laspeyres measure of inflation by the discount store share of the market and their lower prices. The outlet substitution bias -- that is, the gap between the true index and the original Laspeyres index-then works out to be:

(B3) $sd\, B_0 \equiv P_L - P_T = (1+i)$.

For a back-of-the-envelope estimate of the outlet substitution bias, assume that the increased market share (s) captured by low cost retailers in a given year is 2 percent, a rather conservative estimate, and that the percentage discount (d) of the low cost retailer over traditional retailers is 20 percent. Then, if the Laspeyres index $1+i$ was 1.02, the upward bias of this measure over a "true" index would be .0041, or .41 percentage points.

We turn out attention now to the issues of quality change and new goods bias. Every year, statistical agencies find that some of the commodities that they are pricing in various outlets disappear. Although disappearance from one outlet does not mean that the good has vanished altogether from the market, statistical agencies typically require that the good be found and priced in the same outlet, as a way of minimizing any variation in price related to location or quality of service at various outlets. The typical disappearance rate of goods from the outlet where they were previously surveyed is about 20 percent per year.

In many cases, the statistical agency will simply "link in" the new model, a process which involves looking at price changes in the old model up to a point in time, and then after that point, looking at price changes in the new model. After two periods of pricing the new model, the price ratio for the new model can be aggregated or "linked" in with the price ratios of old models that have not disappeared. This approach works if any quality differences between the two models are reflected by the price difference between them. But more typically, the new model has improved efficiency which is not fully offset by its price.

For a rough measure of the bias created here, the true price index is assumed to be

(B4) $P_T \equiv (1-s)(1+i) + s(1+i)/(1+e)$,

where $P_L = (1+i)$ is the Laspeyres index calculated by the statistical agency, s, is the share of commodities that have been replaced by new models and e is the percentage increase in the efficiency of new models that is missed when the new models are linked into the index. Notice that this formulation is parallel to the earlier discussion of outlet substitution bias: there, the weights were the growing market share of discount stores and their price difference; here, the weights are the market share of the new models and their efficiency (or quality) difference.

The *quality change bias* B_Q is then the difference between P_L and P_T, which is:

(B5) $B_Q \equiv P_L - P_T = (1+i)se/(1+e)$.

Assume that inflation as measured by the Laspeyres index is 2 percent, so that $(1+i) = 1.02$. Assume further that the share of commodities that have been replaced by new models (s) is .1, which may be too high for many commodity categories, and that the percentage increase in the efficiency of new models (e) which was missed by the linking procedure is .05, which will be too low for many classes of electronic goods. Then the quality change bias will be .0049, or .49 percentage points.

The appearance of new goods offers an additional problem for a fixed-weight index. Again, such goods can be "linked" into the index over time, but it often takes a period of years before the new good is actually included in the basket. When a new product is' introduced into the market, it generally has a high price which is reduced in subsequent periods. Since statistical agencies do not introduce new goods into their commodity baskets until the new product has become important in the market, they often miss this early decline in price.

For the period before the new good appears, we can follow Hicks (1940; 114) and imagine an imputed price for the new good that would cause consumers to demand zero units of it. Statistical agencies also miss the (imputed) price decline of a new product in the period when the new good makes its first appearance.

In the spirit of the earlier estimates, a rough estimate of the neglect of new goods begins with a true price index, P_T, defined by

(B6) $P_T \equiv (1-(1/2)s)(1+i) + (1/2)s(1+i)(1-d)$,

where $(1+i) = P_L$ is the Laspeyres estimate of overall price change, s is the market share of new goods which have not yet been introduced into the basket of commodities and d is the percentage decline in the prices of the new goods from their initial imputed prices.' The *new goods bias* B_N will be the difference between P_L and P_T:

(B7) sd $B_N \equiv P_L - P_T = (1/2)(1+i)$.

Again assume that the inflation rate is 2 percent, so that $P_L = (1+i)$ is 1.02. Assume that the share of new commodities that are not in the statistical agency basket is .05 and that the average decline in price that was missed was 20 percent. Then, the new goods bias is .0051, or .51 percentage points.

New goods bias is an even more pervasive phenomenon than it may appear at first sight. From the viewpoint of the local market place, the introduction of an increased selection of commodities creates new goods bias even though the newly available commodities are not "new" in a global sense.

The Paasche index under our assumptions is

(B8) $P_P \equiv \{(1-s)(1+i)^{-1} + s[(1+i)(1-d)]^{-1}\}^{-1}$.

We approximate this weighted harmonic mean by the corresponding weighted arithmetic mean so that

(B9) $P_P \cong (1-s)(1+i)+s(1+i)(1-d)$.

Finally, define the true index P_T to be the Fisher index, $P_F = (P_L P_P)^{(1/2)}$ and approximate the geometric mean by the arithmetic mean so that

(B10) $P_T \cong (1/2)P_L + (1/2)P_P \cong (1/2)(1+i) + (1/2)[(1-s)(1+i)(1-d)]$.

For alternative models of the true price index under these conditions, see Diewert (1987; 378).

Traditional index number theory assumes that an unchanging set of products being purchased at an unchanging list of outlets are being aggregated is constant and unchanging over time. Unfortunately, the real world is not so accommodating: new products, outlets and consumers appear; other products. outlets and consumers disappear. This appendix may have left the impression that it is relatively easy for statistical agencies to control for biases in the CPI that result from departures from the assumptions of traditional index number theory. However, all of the methods discussed in the previous section that could be used to estimate biases suffer from a lack of reproducibility. As the U.S. Bureau of Labor Statistics (1997; 19) has noted, it must use methods that are objective, reproducible and verifiable.

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