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Introduction

Robert C. Feenstra and Matthew D. Shapiro

New technologies for processing transactions, together with increases in the ability to store and process information, provide tremendous opportunities for measurement. When data are based on actual transactions, as opposed survey samples of price quotations, revenues, and expenditures, there is the potential for measurement to closely reflect the underlying variable being measured. Basing data on actual transactions also creates opportunities for modeling the behavior underlying the transactions. Such analysis can both improve measurement and be used to study a wide range of economic phenomena.

This volume examines how scanner data can improve price measurement. What are scanner data? Scanner data are electronic records of transactions that establishments collect as part of the operation of their businesses. The most familiar and now ubiquitous form of scanner data is the scanning of bar codes at checkout lines of retail stores. The scanning of goods has a number of purposes for the stores. At a minimum, it provides a relatively automated way for totaling customers' bills. The information collected at the cash registers can also feed information to inform a wide vari-

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Although many persons provided invaluable suggestions for the organization of the conference, the editors would like to take this opportunity to thank William Hawkes for helping to promote the use of scanner data for research and to secure the scanner data used in some of the papers. In particular, the paper by the editors makes use of the ACNielsen academic database (for tuna). The editors hope that continued cooperation among the private and public agencies using scanner data and researchers in academia will ensure that these data are used to address some of the difficult and important issues in the construction of price indexes.

ety of decisions faced by firms regarding operations that include restocking shelves and stores, reordering goods, and scheduling production. It can also be used to monitor the effectiveness of promotions and to evaluate changes in purchase patterns. Stores are increasingly linking the data on individual transactions to other information, for example, through the use of affinity cards that tracks individuals' purchases and offer targeted promotions.

Although most of the papers in this volume focus on retailing, scanner data or their equivalents are collected by many enterprises. One paper in this volume uses extensive databases on prescription drugs transactions. Similar data are collected by all components of the health care system to track patient care and provide the accounting needed for billing and third-party payment. Catalog companies and on-line businesses integrate ordering, delivery, and billing in their information systems. Many nonretail consumer purchases (e.g., utility bills and airline tickets) are accounted for electronically. Increased computerization and networking provide enormous scope for measuring consumer activity transaction by transaction. Finally, electronic data are not limited to the purchases of goods and services. Increased computerization and improvements in information technology also provide opportunities for data collection on production, employment, and payrolls.

Opportunities

Scanner data and other electronic records of transactions create tremendous opportunities for improving economic measurement. Scanner data provide a census of all transactions rather than a statistical sample. Scanner data are collected continuously, rather than at discrete and perhaps infrequent intervals. Scanner data provide simultaneous and consistent observations on both price and quantity. Electronic transmission of scanner data from point of collection to point of analysis can provide for substantial increases in the timeliness and accuracy of observations. Scanner data can allow the process of collecting and summarizing data to be reengineered, with the promise of improvements in the quality and timeliness of official statistics and the potential for providing these improvements at low incremental cost. They allow conceptual as well as functional changes in price measurement.

Census of Transactions

Scanner data provide a record of virtually all transactions. Having a census rather than a sample of transactions has a number of obvious benefits. The most obvious of these is the elimination of sampling error inherent in estimating the average price paid based on a relatively small sample of prices for an item. The limitation on observations per item is only one of the serious constraints imposed by measurement systems that must rely on a sample of prices. Statistical agencies can only sample a limited number of items, and they must sample these items in only a limited number of establishments. The Bureau of Labor Statistics (BLS) uses sophisticated surveys to measure what consumers buy and where they purchase it. It then uses a probability sampling to assure that the items to be priced are a representative sample of consumer purchases. It also collaborates with store managers to use information on sales of items within stores as an input into the probability sampling of items to be priced. Nonetheless, the use of a probability sample inherently involves sampling error. Moreover, the surveys of spending patterns can only be conducted infrequently, and it takes time to introduce the finding of these surveys into the data collection process. In contrast, scanner data can reduce the need to measure prices for a limited number of items at a limited number of outlets.

Surveillance for New Goods

Scanner data provide enormous opportunities for increasing the surveillance of new goods and new outlets by providing timely information on their appearance.[1] The slow incorporation of changes in goods and shopping patterns is an important source of overstatement of inflation by the Consumer Price Index (see Boskin et al. 1996; Shapiro and Wilcox 1996). Eliminating new goods or new outlet bias does not only depend, however, on incorporating new goods rapidly into the sample. Current BLS techniques, for example, link out differences in levels of prices when bringing new establishments into the sample. Scanner data could provide new opportunities to make comparisons of levels of prices or unit values across establishments.

Continuous-Time Data

Scanner data also liberate the data collection process in the time dimension. Prices must be sampled at a particular point in time. These points in time might not be representative of the times when consumers purchased goods (e.g., time of month, day of week, holiday versus nonholiday, time of day, during a sale or promotion). Prices might vary according to time of purchases as firms adjust prices in response to the timing of demand and as consumers simultaneously respond to changes in prices. Prices sampled at fixed points within the calendar or clock might overstate or understate the prices that consumers pay on average.[2] The BLS collects data throughout the month, but not in a way that reflects variation in sales. If there are changes in consumers' spending patterns or in firms' pricing strategies,

1. Hausman (1999) notes how scanner data can be used to alert statistical agencies to the appearance of new goods.

2. Warner and Barsky (1995) find a significant "seasonal" over the week—specifically, that prices are lower on the weekend. Chevalier, Kashyap, and Rossi (2002) find similar price patterns related to weather and holidays.

sampling at fixed points in time could lead to a mismeasurement of the changes in average price paid. By synchronizing the price measurement with the purchase, scanner data eliminate these problems.

Price and Quantity Observed Simultaneously

The simultaneous collection of price and quantity data is another substantial advantage of scanner data over conventional techniques that measure price and revenues separately. At the retail level, prices and sales are collected by entirely different statistical programs. Integrating the data collection of prices and revenues could deliver substantial benefits in terms of cost reduction for both the statistical agencies and the respondents. It would also yield consistent measurement of price and revenues, which would provide opportunities for improving data quality and for increasing their utility for research.

The simultaneous collection of price and quantity data has the potential for greatly improving the ability to construct price indexes that accurately track the cost of living. In the current statistical system in the United States, prices are collected at monthly frequency. These data on price change are available at a very short lag. The Consumer Price Index (CPI) is typically released within a week or two of the end of the month to which it refers. The Consumer Expenditure Survey (CEX) provides the expenditure data necessary for construction of the CPI. These include weights that are used for sampling prices and for aggregating elementary price indexes into the CPI and its components. The CEX has evolved considerably over the years. It now provides a continuous rather than periodic sample of households. The sample size and timeliness of the data have improved over time. Nonetheless, expenditure data are collected at lower than monthly frequency and are only available with a substantial lag.

The lag in the availability of expenditure data creates substantial challenges for price measurement. A fundamental principle of economics is that consumers economize by buying more of goods that become less expensive and fewer of goods that become more expensive. This substitution effect operates at various levels of aggregation: at high levels of aggregation (e.g., chicken vs. beef, medical care vs. entertainment), at low levels of aggregation (e.g., brand X vs. brand Y of canned tuna, branded vs. generic goods), and across outlets (e.g., department stores vs. discount stores, stores having promotions vs. those without them). Price indexes have traditionally been calculated using the Laspeyres formula, which assumes no substitution away from items owing to price changes. In recent years, statistical agencies have made substantial improvements in their methodologies to address substitution effects. For example, the Bureau of Economic Analysis (BEA) now uses chain-weighted indexes that, to a second-order approximation, completely account for substitution effects at a high level of aggregation in the National Income and Product Accounts (NIPA). The

BLS changed its construction of a fraction of its elementary price indexes (from Laspeyres to geometric index formulas) in the CPI to account for low-level substitution of purchases within narrowly defined items. These improvements in the CPI are also reflected in the NIPA because the BEA uses CPI components to deflate personal consumption expenditures. In August 2002, the BLS began publishing the Chained Consumer Price Index that accounts for high-level substitution.

The scope for further improvement in price indexes in how they reflect substitution effects is limited by data availability. To account for substitution, price and quantity (or expenditure) must be measured simultaneously. The existing system of collecting data provides high-frequency information on price but provides information on quantity at low frequency and with greater lags. In the case of the low-level indexes, BLS use of (unweighted) geometric means obviates the need for quantity data by implicitly assuming a unit elasticity of substitution.[3] In the case of high-level substitution, it is possible to project expenditures using an estimate of demand elasticities (see Shapiro and Wilcox 1997) or to report or revise the price index with a lag once expenditure data become available.

Scanner data provide simultaneous data on quantity and expenditure. These data are available with a very short lag and are consistently measured. Having simultaneous quantity and expenditure data creates the possibility of creating price indexes that account for the substitution of consumers away from goods that have price increases. Hence, it is possible to implement superlative index formulas, which account for substitution effects to a second-order approximation, at all levels of aggregation with virtually no time lag. This possibility creates great promise for scanner data, but, as the papers in this volume make clear, the mechanical application of superlative index formulas to scanner data introduces new problems for measurement.

Product Attributes and the Measurement of Quality

Scanner data can be linked with a large range of information in addition to quantities sold. Databases contain detailed information about product attributes, information that has several uses. First, scanner data can be monitored to alert statistical agencies to the appearance of new goods or changes in the attributes of existing goods. Second, as several of the papers in this volume emphasize, information about the attributes of goods can be used to make quality adjustments that are necessary to assure accurate measurement of changes in the cost of living. Information from scanner data can be used to make hedonic adjustments that use many more attributes, larger datasets, and more frequent observations than are available

3. The Bureau of Labor Statistics has found this to be a good assumption on average, but it is likely not to be very accurate when looking across goods.

with conventional hedonic adjustment procedures. Information on product attributes from scanner data can also be used to link observations more accurately when models change and to increase the level of assurance that changes in quality are not linked out of price indexes.

Challenges

The papers in this volume demonstrate that, although scanner data provide significant opportunities for improving on price measurement, incorporating scanner data into the statistical system creates substantial challenges.

First, scanner data pose significant challenges for economic and index number theory. Because scanner data capture individual transactions rather than consumption, they do not map as cleanly into economic aggregates as one might hope. In particular, because of the distinction between purchase and consumption, standard index number formulas cannot be mechanically applied, at least not at high frequency.

Second, the use of scanner data probably would not automatically reduce the cost of collecting price data. Although a price quotation from a scanner record is available at essentially zero marginal cost, the costs of processing scanner data may be high. An agency would have to deal with a tidal wave of information. It would need to address problems of missing data or new goods. Moreover, since much of the cost of pricing an item by hand involves the fixed cost of visiting the outlet, the system of collecting prices by hand would still be quite costly unless all price quotations were made by scanner data.

Third, the use of scanner data requires the participation and cooperation of private firms—both those that are the source of the scanned prices and firms such as ACNielsen, which collects and processes these data. To assure the continuity of the statistical system, the statistical agencies must be assured of long-term, consistent, and timely access to the information need to construct price indexes.

Fourth, the availability of more data does not always lead to better analysis. The electronic economy creates a flood of information. Statistical agencies must develop new modes of operating to convert the huge flow of information into useful statistics.

Summary of the Conference

This volume contains papers originally presented at the Conference on Research in Income and Wealth (CRIW) meeting "Scanner Data and Price Indexes" on 15–16 September 2000 in Arlington, Virginia. The CRIW brings together experts from the statistical agencies and academics with an interest in measurement. The papers in this volume give a good picture of both the promise and the challenge of using scanner data to produce economic statistics.

Scanner Data in Official Statistics: Advancing the State of the Art

William J. Hawkes and Frank Piotrowski present an invaluable case study of using scanner data for price measurement of ice cream. Their paper begins with a discussion of how scanner data can be used to improve price measurement. It also traces important conceptual and practical differences between the ways the CPI program and the Scantrack data system view the markets and goods—ice cream in particular. The paper's analysis is based on a virtual census of retail purchases of ice cream in the United States in 1999. They find that the CPI quite closely tracks the change in the price of bulk ice cream, although this price change is not representative of the entire ice cream category in Scantrack. As noted above, scanner data provide substantial scope for measuring quantities as well as price. This paper is the only one in the volume to have comprehensive coverage for a good. It finds that CEX understates sales by almost 20 percent. Hawkes and Piotrowski also provide an indication of the range of data available for hedonic adjustment. For ice cream, the ACNielsen Product Reference codes over fifty attributes. The impression the authors leave is that a substantial amount of product-specific expertise would be required to make use of such data.

The statistical agencies have substantial research in progress on the use of scanner data for price measurement. This volume includes three reports on this research, from the U.S. Bureau of Labor Statistics, from the U.K. Office for National Statistics, and from Statistics Canada.

The BLS has a pilot project to investigate the feasibility of incorporating pricing information from scanner data into the monthly production of the CPI. This pilot is based on the market for breakfast cereal in New York. The paper by David H. Richardson makes two broad contributions. First, it provides an overview of the use of scanner data in the statistical system based on the actual experience of using them to construct a price index designed to be a practical alternative to a price index based on conventionally collected data: Scanner data are continuous, whereas CPI price observations are collected at particular times of the month, days of the week, and times of the day. Scanner data represent transactions, whereas CPI price observations are based on quoted prices (e.g., the price of a box of cereal on the shelf) whether or not there is a transaction at that price. The BLS knows the exact location of a price quotation, whereas the scanner data are currently anonymous. This anonymity complicates the addition of the appropriate sales tax to the transaction. New procedures are needed for imputing missing prices (see also the paper by Ralph Bradley in this volume) and for cleaning data.

Second, the paper compares the New York price index for breakfast cereal from the CPI program to various indexes computed from the scanner data. The indexes based on scanner data have a similar trend to the CPI index over 1999 to 2000. The CPI is substantially more variable. During the first part of the sample, it runs ahead of the indexes for scanners, whereas it runs behind during the second half. Of the scanner indexes, the superlative indexes increase faster than the geometric index. Given that the elasticity of substitution between different types of cereal is likely to be higher than 1, one would have expected the superlative indexes to grow more slowly. This difficulty of mechanically implementing formulas for price indexes is one of the main themes of this volume.

David Fenwick, Adrian Ball, Peter Morgan, and Mick Silver discuss the U.K. Office for National Statistics's experience in comparing scanner data with conventionally collected data from its Retail Price Index (RPI). This experience highlights another theme of this conference—that the promise of scanner data is perhaps more an increase in quality of price measurement than simply an alternative means to collect data that would otherwise be collected by hand. In contrast with the BLS's pilot, which used breakfast cereals, the U.K. study examines high-unit-value consumer durables. An aim of the study is to evaluate whether scanner data can help improve the representativeness of items priced. In consumer durables, there is substantial heterogeneity in attributes of items, models and items change frequently, and model changes and price changes interact through sale pricing of old models and price changes that occur when new models are introduced. Fenwick and his colleagues find that the universe of scanner data provides different measures of price change than the subset matched with the items in the RPI over the several months compared. However, there is no general lesson. For some of the goods, the RPI-based sample has greater price increase than the scanner universe, whereas the opposite is true for other goods. The authors' recommendation is that scanner data be used for weighting price quotations, either through quotas based on scanner data or the weighting of price quotations based on sales measured by scanners. They do not go so far as to recommend using unit values from scanners to replace price measurements for these goods.

Robin Lowe and Candace Ruscher's paper reports on Statistics Canada's research on the price of televisions. Technical change has led to both price declines and quality improvements in televisions. As has just been noted, the interactions of these quality changes, changes in models, and changes in prices pose very difficult challenges for the statistical agencies in obtaining accurate measures of prices for consumer durables. The paper first discusses the current practice of Statistics Canada for dealing this these problems and uses a relatively long span of data, from 1990 to 1997, to document how different procedures have noticeable implications for measures of price change. The paper then examines an experimental data set using scanner data for televisions over a two-year period. It discusses how scanner data can alert the statistical agency to the existence of new models, but it also highlights the practical difficulties of using these data to compute price indexes. As with prices for the official CPI, these new models must be linked in to the existing database. Doing so requires assumptions about whether or not their attributes are comparable to the ones they replace. The authors investigate using regression analysis as an alternative to making judgments about this issue. For this approach to be practical, substantial data on attributes of the models would need to be collected, and the regression analysis would need to be carried out quickly. It would not be practical to perform such analysis for all goods in the scanner database, so the agency would need to resort to sampling of these data.

In addition to reports on these specific projects, the volume also includes a roundtable discussion of ongoing projects at the statistical agencies. Participants in the roundtable are Dennis Fixler (BLS), John S. Greenlees (BLS), David Fenwick (U.K. Office of National Statistics), Robin Lowe (Statistics Canada), and Mick Silver (Cardiff University). This discussion highlights a number of the key findings of the pilot projects relating to variance, replication of official practice, and quality adjustment. It also raises the issues of the pecuniary and practical issues raised by the use of scanner data. The pecuniary cost of collecting prices by visiting stores is quite low, especially for the marginal price quotation. Scanner data are produced commercially and typically are quite expensive to purchase. Hence, using scanner data, especially when workers from statistical agencies must visit stores for other purposes (e.g., to get other price quotations, to get information about products, etc.) might add to the cost of the statistical system, particularly during a period of transition to increased use of electronic data. Also, the statistical agencies would need to develop long-term contracts with the commercial sources of scanner data to assure the timeliness and continuity of its data sources.

Aggregation Across Time

Conventional price measurement typically involves some averaging over time. Equilibrium prices and quantities, however, vary continuously as sellers strategically set prices and as consumers respond to price variation. By making actual rather than average transactions observable, scanner data both create the opportunity for studying these market outcomes and provide challenges for mapping transactions data into price index numbers.

Robert C. Feenstra and Matthew D. Shapiro study the behavior of price indexes constructed from high-frequency scanner data. Jack E. Triplett reflects on a number of issues of price index construction and uses a small data set to show how consumer shopping behavior can dramatically alter the true price paid relative to what a price index based on survey sampling might measure. Feenstra and Shapiro find that mechanical application of standard index number formulas to these weekly data lead to surprising results. Superlative price indexes should grow more slowly than fixed-weighted indexes because they are designed to account for substitution by consumers away from goods whose price is increasing. Yet, in their sample of weekly data, the superlative indexes show increases relative to the fixed-weight indexes. The studies by the statistical agencies in this volume provide similar examples of unexpected behavior of superlative indexes.

The papers by both Feenstra and Shapiro and by Triplett note that movements in high-frequency data on purchases by consumer can be dominated by shopping behavior rather than consumption behavior. Even goods that are nondurable may be storable, so the high-frequency purchases might be dominated by consumers' economizing by buying (rather than consuming) when the price is low. This consumer behavior is also affected by strategic behavior of the stores, especially nonprice promotion (e.g., advertising). These promotions cause bursts of purchases at times when the price may not be the lowest, leading to apparent failures of the law of demand and the surprising behavior of superlative indexes. Feenstra and Shapiro present a model due to Betancourt and Gautschi (1992) that distinguishes shopping and consumption. It implies an index number formula that compares prices over entire planning horizons (e.g., from one year to the next). This formula appears to work well in practice. They also provide econometric evidence that consumers respond to sales and promotions as the theory predicts.

Using Price Data to Study Market Structure

Robert Barsky, Mark Bergen, Shantanu Dutta, and Daniel Levy use an original data set that combines retail and wholesale data for a grocery store chain. The differences in prices between branded goods and store labels can provide an estimate of the markup. Since store labels will not be sold at less than marginal cost, the ratio of the retail prices of branded to store labeled goods is a lower bound on the markup of the branded goods. Moreover, since they have data on the wholesale prices of both goods, they can provide additional estimates of the markups that include the cost of retailing. They find that markup ratios can be substantial—over 3 for toothbrushes and over 2 for soft drinks. There is also substantial heterogeneity in markup ratios, with some being quite low and most ranging from 1.5 to 2.

The existence of substantial markups has very important implications for industrial organization and macroeconomics. It also has important implications for price measurement and the use of scanner data. That markups can be large also means there is substantial scope for them to vary over time. (If perfect competition reigned supreme, not only would markups be low, but they would always be the same.) There are good reasons to expect that markups should vary with the level of demand (see Rotemberg and Saloner 1986). Demand can vary over the business cycle, but also at much higher frequency. Warner and Barsky (1995) emphasize how markups can change over the days of the week depending on the shopping behavior of consumers, and Chevalier, Kashyap, and Rossi (2002) make the same point for the time of year. Since scanner data record prices continuously, they will capture the changes in prices resulting from changes in the markup that may occur at high frequency. Statistical agencies could miss some of these price changes to the extent that price data are collected during normal business hours and days.

One of the most difficult practical and conceptual problems for statistical agencies is the incorporation of new goods into the price index. A key practical difficulty is monitoring the arrival of new goods and the selectivity and bias created by lagged incorporation of successful new goods. Scanner data can be helpful in this regard because they can provide more timely information about the arrival of new goods than can surveys of consumers. John S. Greenlees emphasizes this point in his roundtable discussion. Nonetheless, the conceptual issues of how to incorporate them into a price index remain. Ernst R. Berndt, Davina C. Ling, and Margaret K. Kyle study the interactions of prescription versus over-the-counter versions of the same pharmaceutical compound during the period around the expiration of the patent for the compound. They contrast different techniques for accounting for the value of new goods—one by Feenstra (1994, 1997), which estimates the elasticity of substitution across the goods, and one by Griliches and Cockburn (1994), which relies on a distribution of tastes across consumers for branded versus generic versions of the pharmaceuticals. Their analysis makes use of monthly data on shipments of the compounds by their manufacturers (quantity, revenue, and promotional information) collected by IMS Health. Like scanner data for a grocery store, these data provide a census of transactions for the goods in question. The authors find that marketing is very important in explaining the relative success of pharmaceuticals and the demand for them following patent expiration. They also provide a comparative analysis of the Feenstra and Griliches-Cockburn procedures for incorporating new goods into price indexes. They find that functional form assumptions, although not inherent to Feenstra's procedure, have significant impact on the calculations. They speculate that the simple functional forms used by Feenstra might operate better at higher levels of aggregation (e.g., new classes of pharmaceuticals instead of close substitutes within a class).

Measuring Change in Quality and Imputing Missing Observations

The paper by Mick Silver and Saeed Heravi examines alternative approaches to using scanner data for adjusting prices for quality change. It contrasts three approaches: matching ofsimilar models; hedonic regression using a limited set of dummy variables for characteristics; and hedonic regression using the larger set of characteristics readily observed in scanner data. The paper examines data for 1998 on washing machine sales. The scanner data provide model numbers for each transaction, which are keyed to information about the characteristics of the models from the manufacturers. For the authors' data, the three approaches to quality adjustment perform not dissimilarly. The authors extend their framework to discuss the problem of missing data as confronted by statistical agencies in practice. In contrast with the case of cereal examined by Bradley, missing data for consumer durables are likely to occur with model changes that require hedonic adjustments.

Erwin Diewert's discussion of Silver and Heravi's paper developed into an examination of the foundations of hedonic price adjustment, which is included as a chapter in this volume. It shows how simple linear models are hard to justify with economic theory. It also shows that the traditional practice of statistical agencies replicates exact hedonics under some circumstances. Additionally, it uses the economic analysis to inform econometric practice for estimating hedonic relationships.

Scanners record transactions. If a good is not sold during a specific week at a specific outlet, there will be no information about its price. Since goods are very narrowly defined (there are different Universal Product Codes for slight variants of products—e.g., the 16-oz. vs. the 20-oz. box of Cheerios), there is a substantial probability that observations will be missing. In contrast, the CPI will price an item if it is on the shelf, regardless of whether it is sold. It will generate a missing observation if it is stocked out. A stock out could mean either that the item is not available (and therefore not sold) or that it is sold out (and therefore had possibly substantial sales). Ralph Bradley investigates alternative methods for dealing with these missing observations. In particular, he proposes an econometric procedure that assigns a virtual price and contrasts it to other procedures (carrying forward the last observation, using unit values at a higher level of aggregation that does not have missing values, the BLS method of imputation). For his sample, the procedures lead to similar indexes over time, although the variability of the indexes differs.

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