

Content Articles in Economics

In this section, the *Journal of Economic Education* publishes articles concerned with substantive issues, new ideas, and research findings in economics that may influence or can be incorporated into the teaching of economics.

HIRSCHEL KASPER, Section Editor

Teaching Chain-Weight Real GDP Measures

Miles B. Cahill

Abstract: In 1996, the Bureau of Economic Analysis (BEA) changed the method used to calculate measures of real GDP from a Laspeyres or Paasche index to a Fisher ideal index, also called a chain-weight index. Even though this is a significant change in approach and has resulted in extensive revisions of reported statistics, many authors of intermediate-level textbooks treat this topic casually, if at all. In this article, the author presents two applications in which this topic can be explored more thoroughly, with the help of spreadsheet software. One exercise introduces the concept of the chain-weight index by comparing it to Laspeyres, Paasche, and ideal indexes with the use of utility analysis. The second exercise is a step-by-step process to calculate chain-weight index statistics.

Key words: chain-weight GDP, spreadsheets, teaching economics

JEL codes: A22, A20, O47

Unfortunately, the method changes in the national income and product accounts have received little or no attention from economists in academia. However, the new approach has important implications for the measurement of economic growth and the interpretation of real-dollar estimates of gross domestic product and its components.

—Rossiter

In 1996, the Bureau of Economic Analysis (BEA) introduced chain-weight (also known as Fisher ideal) measures of real gross domestic product (GDP) output and price indexes. The new measures are designed to correct for the substitution bias problem associated with the fixed-weight Laspeyres and Paasche

Miles B. Cahill is an associate professor of economics at the College of the Holy Cross (e-mail: mcahill@holycross.edu). The author gratefully acknowledges helpful suggestions from George Kosicki, Kim Craft, Melaku Lakew, Bill Becker, Hirschel Kasper, Kim Sosin, and anonymous referees.

indexes used previously. Although this bias has been long known to national income accountants, in recent decades this substitution bias became a serious problem, mainly because computer and high-technology goods prices fell dramatically as sales increased substantially (Landefeld and Parker 1995). It is important to note that the chain-weight real GDP figures have other biases, including those related to quality change, new products, and aggregation issues. Several sources contain discussions of these biases in detail with regard to the consumer price index (e.g., Boskin et al. 1998; Schultze and Mackie 2002), and many of the arguments are valid for real GDP.¹

The impact of these changes is surveyed by Rossiter (2000), who introduces the bias issues associated with fixed-weight indexes, discusses generally how chain-weight indexes are formed, and explains how chain-weight data are best used. The latter topic is especially important in light of the fact that chain-weight GDP components are not additive. Finally, Rossiter provides a brief overview of how the revised estimates have affected historical data.

Rossiter's (2000, 363) quote above highlights the fact that even though chain-weight measures have been the standard way to measure real GDP for the last several years, many intermediate-level macroeconomic textbooks do not provide a thorough explanation of the chain-weight method. In appendix Table A1, I present the results of a survey of 12 well-known textbooks. Five of the textbooks provide no explanation of chain-weight measures, 2 provide short overviews that minimize their importance, 2 provide significant descriptions in a sidebar or appendix, 2 provide short descriptions in the main text, and only one (Gordon 1998) provides a detailed description within the main text and presents fixed-weight figures in the data appendix.

In this article, I build on Rossiter's work (2000) by presenting two ways to teach chain-weight concepts in intermediate-level courses. One exercise introduces the concept of the chain-weight index by comparing it to Laspeyres, Paasche, and ideal indexes with the use of utility analysis. The second exercise is a step-by-step process for calculating chain-weight index statistics. The applications demonstrate that teaching chain-weight measures provides an opportunity to explore some fundamental economic concepts and to learn to use important spreadsheet functions.² The spreadsheets for the exercises may be downloaded from this article's supplementary Web page at <http://www.holycross.edu/departments/economics/mcahill/jee/jee-paper.html>. This Web page also includes the spreadsheets used to generate the other figures in this article, student instruction sheets for constructing the exercises, the links referred to in this article, and a short list of other useful links for teaching economics using spreadsheets.

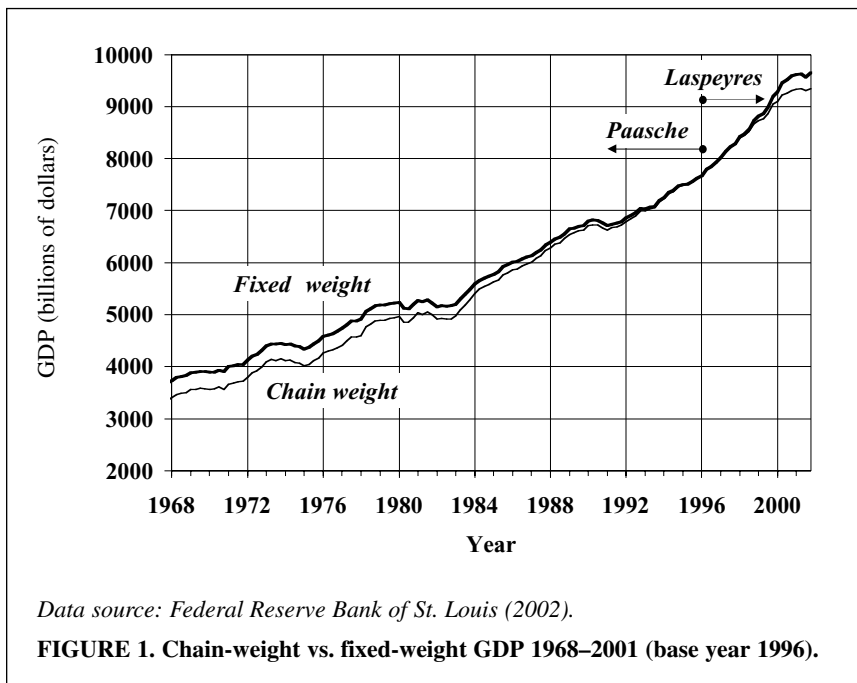
CHAIN-WEIGHT INDEXES VERSUS FIXED-WEIGHT INDEXES

Real GDP is an index of the quantity of production for a given year relative to a base year. Whereas with a price index, the base-year's index value is usually set at 100, the real GDP index base-year value is usually scaled to nominal GDP.³ The traditional fixed-weight method of computing real GDP involves using the base-year's prices as weights in the index to compute GDP for every other year.

Although the fixed-weight method makes intuitive sense, it creates a substitution-effect bias. When relative prices change, households substitute toward purchasing relatively cheaper goods, causing relative production to rise for those products. As a result, goods whose relative prices fall over time tend to experience relative increases in production and vice versa. With a fixed-weighting scheme, this means that for years after the base year, the index weight (i.e., the base year's price) for goods with the largest increases in production tend to be relatively large compared to contemporaneous weights and vice versa.⁴ This means that GDP growth is overstated for years after the base year. For years before the base year, goods with the largest increases in production have relatively low base-year price weights, and so GDP growth is understated. This in turn creates a further problem: When the base year is periodically changed, historical real GDP growth figures are adjusted downward.

The chain-weight method corrects for the bias by taking the geometric average of two fixed-weight statistics: the GDP growth rate calculated with the current year's prices (the end-of-period prices) and the previous year's prices (beginning-of-period prices).⁵ Thus, it is the average of a Laspeyres and a Paasche growth quantity index. This type of index is also known as a Fisher ideal index. When applied to price indexes, the Fisher ideal index provides a good approximation of an ideal cost of living index (Diewert 1998, 1997, 1976; Stone and Paris 1952). One of the following teaching applications demonstrates this attribute of Fisher ideal quantity indexes.

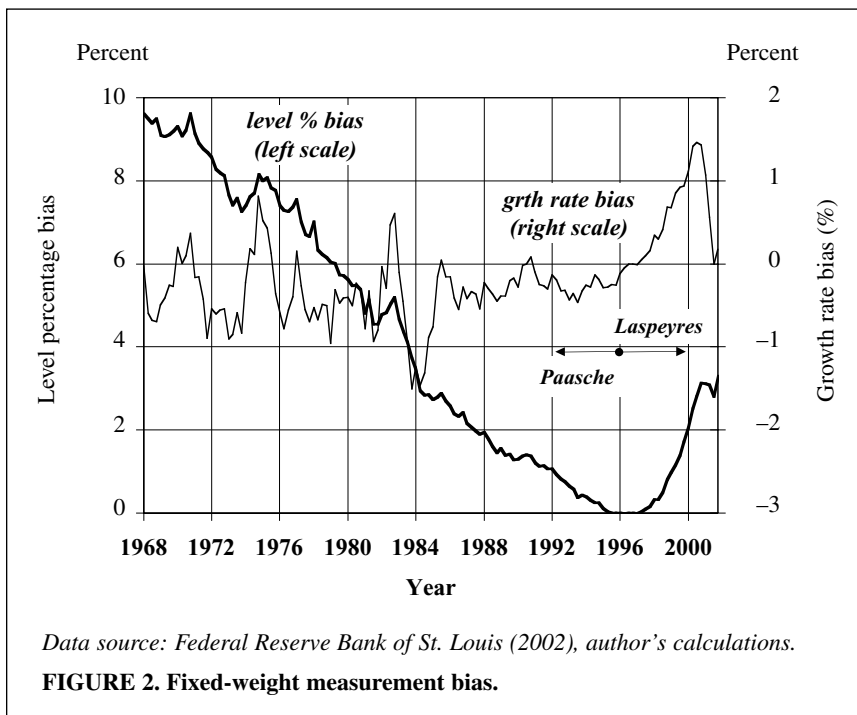
I depict fixed-weight and chain-weight GDP measures in Figure 1 for all



quarterly data available following the most recent comprehensive National Income and Product Account (NIPA) revision through the end of 2001. Note that with the exception of the base year, the fixed-weight measure overstates real GDP, and the bias worsens further in time from the base year. This consequence is the result of fixed-weight and chain-weight real GDP values using the same base-year benchmark, but because of the substitution effect, fixed-weight GDP grows faster after the base year and slower before the base year. The magnitude of the bias grows over time because relative price changes are more extreme further from the base year.

The biases associated with the fixed-weight measure are shown in Figure 2. About 35 years ago, the bias was approximately 10 percent of GDP; in the fourth quarter of 2001 (with the base year about 5 years in the past), the bias was about 3 percent. The bias in the GDP growth rate is mostly negative before the base year and positive after the base year (Figure 2). During periods of recession (e.g., 2001), the bias reverses itself as both prices and quantities fall. The average of the absolute value of the bias is 0.4 percentage points, and the bias ranges from -1.5 percentage points to 1.3 percentage points—a significant bias in a single quarter’s GDP figure.

Chain-weight indexes are explained more thoroughly in several sources, including Rossiter (2000). The BEA’s national accounts Web page (<http://www.bea.gov/bea/an1.htm>) makes available a series of articles from the *Survey of Current Business* concerning the adoption of the chain-weight method. Landefeld



and Parker (1995) provide a detailed description in the article that introduced the chain-weight method. This article contains a sidebar note that provides a clear two-good numerical example that illustrates the shortcomings of the fixed-weight methods and shows how the chain-weight method corrects for the problems.⁶ Landefeld and Parker (1997) detail the effect of changing the method on NIPA statistics.

TEACHING CHAIN-WEIGHT MEASURES

Spreadsheet exercises facilitate the teaching of two key concepts in index methods: how the substitution bias works and how chain-weight measures are computed. The first exercise uses demand functions derived from a utility function to generate the substitution bias, demonstrates the effect of the substitution bias by computing the Laspeyres and Paasche quantity indexes, and constructs an ideal quantity index using utility analysis. The exercise shows that the chain-weight (Fisher ideal) index is a compromise between the Laspeyres and Paasche approaches and a good approximation of the ideal index. This example is useful because it clearly depicts the substitution bias at work from first principles and demonstrates the desired feature of the chain-weight index. The second example is a more practical example of a chain-weight GDP calculation: It constructs a chain-weight quantity (real GDP) index from data using a multistep procedure. The first example is based on a framework in Cahill and Kosicki (2000), and the latter is very close to an example available in the Web supplement to Cahill and Kosicki (2000).

Understanding the Substitution Bias and the Fisher Ideal Index with Utility Theory

The initial setup of this example follows the initial setup of section 3 of Cahill and Kosicki (2000), which compares price indexes. Consider an economy with one consumer with a Cobb-Douglas utility function over two goods (x and y), $U = x^a y^b$, where $a > 0$, $b > 0$. Denote the exogenously determined prices of the goods with p_x and p_y and, for expositional purposes, assume the consumer has a fixed level of income (I). The individual maximizing utility has demand functions $x^* = [a/(a + b)](I/p_x)$ and $y^* = [b/(a + b)](I/p_y)$. Assume in this short-run scenario that production equals demand. The top left-hand corner of Figure 3 depicts this information set up on a spreadsheet where parameter values are typed into column B: ($a = b = 1$, $p_x = \$4.00$, $p_y = \$1.00$, $I = \$400$), and Excel formulas are used to calculate the values of x^* , y^* , and U . Note the relative price $p_x/p_y = 4$.

Column D depicts the same information copied, with both prices increased in such a way that the price ratio is changed to $p_x/p_y = 3$. With constant nominal income, note that the demand for goods x and y has fallen, but the demand for y has fallen by more in percentage terms as the price of y has increased by more in percentage terms. On the spreadsheet, the Laspeyres quantity index growth rate figure is computed by finding the cost of the new consumption bundle at the original prices and dividing by the cost of the original bundle at the original prices and subtracting one. The Paasche quantity index growth rate is computed similarly, except the new prices are used. At this point, the problem with fixed-weight

	A	B	C	D	E	F
1		Original values		New values	Use original values to find ideal	quantity index
2	a	1	copy & paste,	1		1
3	b	1	then update prices	1		1
4	p_x	\$4.00		\$4.20	\$4.00	
5	p_y	\$1.00	→	\$1.40	\$1.00	
6	I	\$400		\$400	\$329.91	by adjusting
7	x^*	50		47.62	41.24	income
8	y^*	200		142.86	164.96	←
9	U	10,000		6,802.72	6,802.72	Solver drives this
10						cell to new U
11				Laspeyres quantity growth rate	-16.7%	Ideal quantity growth rate
12				Paasche quantity growth rate	-18.4%	-17.5%
13				Chain-weight (Fisher ideal) quantity growth rate	-17.5%	

FIGURE 3. Utility analysis of chain-weight index.

indexes should be clear: Under two reasonable sets of assumptions, two different figures result. Furthermore, the Paasche index method gives the stronger decrease in real GDP; this is to be expected as it uses the new prices, which implicitly gives a higher relative weight to the good whose production decreased the most. Experimentation with different utility functions (exhibiting substitution) and price changes can demonstrate this general result. The chain-weight (Fisher ideal) index is the geometric average of the Laspeyres and Paasche price indexes and appears to be a reasonable compromise.⁷

To understand better why the chain-weight measure is indeed a sound method, consider the concept of a (true) ideal index. If an ideal price index (in percentage-change form) is the percentage increase in income at final conditions necessary to leave a consumer at exactly the same level of utility after a price change, a true ideal quantity index (in percentage terms) is the percentage of income taken away from a consumer at initial conditions necessary to leave the consumer at the same level of utility after the price change.⁸ That is, it is the change in income that is equivalent to the change in utility.⁹ Intuitively, it is a measure of the change in real income because it is the percentage of base-year income lost when prices rise after accounting for substitution effects in changes in demand. To compute such an ideal quantity index on the spreadsheet, one copies the original scenario information (column B) to column E, and one uses the Excel Tools/Solver command to set the utility level in column E to the level in column D (after the price change).¹⁰ The ideal quantity growth rate is the percentage difference in income from the original level I . Note that the true ideal quantity growth rate is very close to the chain-weight (Fisher ideal) growth rate. This mirrors the results of Diewert (1976) and Stone and Paris (1952) that a Fisher ideal price index approximates a true ideal price index.

Chain-Weight GDP Calculations

In this section, I present a step-by-step process for computing the chain-weight GDP measures using price and quantity data. This process is useful because the equation that directly defines chain-weight GDP is difficult for students to under-

stand, let alone use. If Y denotes real GDP, p denotes the vector of product prices, q denotes the vector of product quantities, and t denotes the time period, chain-weight real GDP can be expressed as the following:

$$Y_t = \sqrt{\left(\frac{\sum p_{t-1} q_t}{\sum p_{t-1} q_{t-1}} \right) \left(\frac{\sum p_t q_t}{\sum p_t q_{t-1}} \right)} \times Y_{t-1} . \quad (1)$$

Note that the first term under the square root is a Laspeyres quantity index (as it uses the previous-period's prices), and the second term is a Paasche quantity index (as it uses end-of-period prices). The BEA does not directly calculate chain-weight GDP using an equation like equation (1), but the actual method employed by the BEA to calculate real GDP growth is also probably impractical at the intermediate level. The BEA first uses a chain-weight price index to deflate nominal figures (rather than calculating real figures directly from price and quantity data), and this price index is difficult to calculate directly. The process outlined below gives equivalent results to equation (1) and the BEA process but is more intuitive.¹¹ It is the method suggested in numerical examples provided by the BEA (Landefeld and Parker 1995). Unfortunately, these steps require repeated, tedious calculations. A spreadsheet can help to keep the calculations organized, increase accuracy, and make the assignment less time consuming.

The steps are outlined in the spreadsheet depicted in Figure 4. Column A labels the rows, and columns B through F display five years of data. Rows 3–8 display price and quantity data for two goods (it is straightforward to add more goods), where figures are chosen to depict the relative price for good 1 to be rising and its relative production falling.¹² Row 9 calculates nominal GDP.

The first goal is to calculate the chain-weight growth rate of real GDP for each year. To accomplish this, it is first necessary to calculate the annual growth rate of real output using the current year's prices as weights (row 11) and then the annual growth rate of real output using the previous year's prices as weights (row 12). These are growth rates associated with Paasche and Laspeyres indexes, respectively. The chain-weight real-growth rate is then computed as the geometric mean of these two fixed-weight real-growth rates (row 13). The next step is to choose a base year and calculate real GDP figures for each year by using the chain-weight real-growth rates. In Figure 4, year three is chosen as the base year, so nominal GDP in year three is declared chain-weight real GDP. Real chain-weight GDP in year four is calculated by adding the chain-weight growth to year three's real GDP, and chain-weight GDP in year five is similarly calculated using its chain-weight growth rate and year four's real GDP value. Year two's real chain-weight GDP level is calculated by dividing year three's real GDP figure by year three's growth rate plus one, and year one's real GDP is calculated similarly. It is here that the term chain-weight shows its relevancy: year five's real GDP contains price information on years five and four (through the chain-weight growth rate calculation) and years four and three (through year four's calculation). Any given year's real

	A	B	C	D	E	F
1		Year				
2		1	2	3	4	5
3	Prices					
4	Good 1	\$20	\$21	\$22	\$23	\$24
5	Good 2	\$60	\$59	\$58	\$57	\$56
6	Quantities					
7	Good 1	75	76	77	78	79
8	Good 2	25	30	35	40	45
9	Nominal GDP	3000	3366	3724	4074	4416
10	Chain weight GDP calculations					
11	Real growth rate of output (Paasche index) (current year's prices used as weights)		10.36%	9.14%	8.18%	7.39%
12	Real growth rate of output (Laspeyres index) (previous year's prices used as weights)		10.67%	9.39%	8.38%	7.56%
13	Real growth rate of output (chain-weight)		10.51%	9.27%	8.28%	7.48%
14	Real chain-weight GDP (Year 3 = base year)	3084.0	3408.2	3724.0	4032.3	4333.7
15	Fixed weight GDP calculations					
16	Real fixed-weight GDP (Year 3 = base year)	3100	3412	3724	4036	4348
17	Real growth rate of production (fixed base-year weight)		10.06%	9.14%	8.38%	7.73%
18	Growth difference (chain — fixed)		0.45%	0.12%	-0.10%	-0.25%
19	Inflation calculations					
20	Chain-weight GDP deflator	0.973	0.988	1.000	1.010	1.019
21	Fixed-weight GDP deflator	0.968	0.987	1.000	1.009	1.016
22	Inflation rate (fixed-weight)		1.94%	1.37%	0.94%	0.62%
23	Inflation rate (chain-weight)		1.53%	1.25%	1.04%	0.85%
24	Inflation difference (chain — fixed)		-0.41%	-0.11%	0.09%	0.24%

FIGURE 4. Chain-weight GDP calculation.

GDP figure contains a chain of prices back to the base year. Finally, the chain-weight GDP deflator (called the chain-weight price index) can be found by dividing the nominal GDP figure by the chain-weight real GDP figure (row 14). Because it uses chain-weight real GDP data, it also contains price information chaining to the base year. Chain-weight GDP data are presented as chained base-year dollars; however, they actually employ a weighted average of prices from any given year to the base year.

An interesting follow-up example is to calculate fixed-weight real GDP, real GDP growth, and the GDP deflator using the base-year prices and then compare the results to the chain-weight results. If the figures are chosen carefully (as in Figure 4), the figures will exhibit the substitution bias. Other rows have been added to calculate inflation rates implied by the fixed-weight and chain-weight deflator.

CONCLUSION

The chain-weight method is now used by the BEA to calculate official national income and product account statistics. Although it is more complex and less convenient to teach than the standard Laspeyres or Paasche fixed-weight method, it is important for undergraduate students to understand how GDP and related statistics are calculated.¹³ Whereas the chain-weight method is certainly more

technical, teaching it creates an opportunity to explore other important economic concepts and to see them at work. Most obvious, the chain-weight calculations demonstrate the importance of the substitution effect, both theoretically and empirically. The discussion also highlights the importance of computers in the current economy, as it was the growing high technology sector that led to the switch to chain-weight measures. Finally, the exercises introduce both rudimentary and sophisticated spreadsheet operations, and students are likely to use spreadsheets in other courses and in future employment.

APPENDIX

TABLE A1. Coverage of Chain-Weight Measures in Intermediate-level Macroeconomics Textbooks

Textbook	Chain-weight material
Abel and Bernanke (2001)	Solid overview in sidebar (pp. 47–48)
Barro (1997)	Short overview (p. 35)
Blanchard (2000)	Solid overview in appendix (pp. 36–37)
DeLong (2002)	None
Dornbusch, Fischer, and Startz (2001)	None, except one footnote reference to <i>Survey of Current Business</i> articles (p. 32)
Farmer (2002)	None
Froyen (1998)	One small section with quote “The new chain-weighted measures do not differ greatly from previous measures . . .” (pp. 24–25)
Gordon (1998)	Gives solid overview but reports fixed-weight data in appendix (pp. 50–51, 53)
Hall and Taylor (1997)	None
Mankiw (2003)	One small section, brief description with quote: “For most purposes, however, the differences are not important.” (p. 23)
Miles and Scott (2002)	None
Williamson (2002)	Short overview and example (pp. 50–55)

NOTES

1. See also the Symposium on “Measuring the CPI” in the winter 1998 issue of *The Journal of Economic Perspectives*, which contains Boskin et al. (1998) and Diewert (1998) among several articles, and the May/June 1997 issue of the Federal Reserve Bank of St. Louis *Review*, which contains Diewert (1997) among several other articles as part of the proceedings to the conference “Measuring inflation and growth.”
2. See Cahill and Kosicki (2001) for a review of issues associated with using spreadsheet applications in the classroom.
3. The BEA also reports real GDP in quantity index values with base year set at 100 in section 7 of the data tables in *Survey of Current Business*. Rossiter (2000) relates these data to the more common base year set at nominal GDP figures.
4. In years before the base year, traditional real GDP figures are a Paasche index; in years after the base year, the figures are a Laspeyres index.

5. This correction is, of course, imperfect.
6. This example is repeated in the Gordon (1998) textbook.
7. See Diewert (1997; 1998) and references therein for details. There are alternative superlative indexes (e.g., the Törnqvist-Theil index) that also address the substitution bias. However, Diewert (1997; 1998) asserts that the Fisher ideal is a superior choice based on a number of criteria. The geometric mean is preferred to the arithmetic mean because the geometric mean has a time reversibility property. This means that for any given price change from the base year to another given year, the price change from the given year back to the base year is the reciprocal of the original price change (Diewert 1997; 1998). Note that with negative growth rates, the negative geometric average value must be forced, as Excel's SQRT command automatically displays only the positive root.
8. Alternatively, it can be expressed as the percentage of income given to a consumer after the price change necessary to leave the consumer at the same level of utility after the price change. For certain types of utility functions (i.e., when preferences are homothetic), the two definitions will give identical results. However, if preferences are not homothetic, the two definitions may yield different results. In such cases, there is no single ideal quantity (or price) index. The spreadsheet file for Figure 2 on the supplementary Web page contains an example of this alternative formulation. The Cobb-Douglas preferences used are homothetic.
9. The supplemental Web page contains an exercise that graphically depicts the formulation of the ideal price index on a two-good indifference curve diagram.
10. See Cahill and Kosicki (2000) for details on using Solver. Tools/Goal Seek may also be used but may not be as accurate. Alternatively, it is possible to solve the utility function analytically for the income level and input the formula into Excel.
11. Rossiter (2000) presents an alternative way to build a chain-weight GDP figure. Rather than first computing growth rates and then imputing levels, index values are first computed from the raw data, which is presented in a matrix. However, the results are equivalent.
12. The figures are carefully chosen, but an example such as Figure 3 can be used to generate quantity data given exogenously determined prices.
13. Chain-weight figures gained new prominence in 2000 when the Federal Open Market Committee announced it uses the personal consumption expenditures (PCE) chain-weight price index as its measure of inflation, rather than the CPI.

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