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INTRODUCTION TO *MEASUREMENT WITH THEORY*

WILLIAM A. BARNETT
University of Kansas

W. ERWIN DIEWERT
University of British Columbia

ARNOLD ZELLNER
University of Chicago

This paper is the introduction to the *Macroeconomic Dynamics* Special Issue on Measurement with Theory. The Guest Editors of the special issue are William A. Barnett, W. Erwin Diewert, Shigeru Iwata, and Arnold Zellner. The papers included are part of a larger initiative to promote measurement with theory in economics.

Keywords: Measurement, Index Number Theory, Aggregation Theory

1. INTRODUCTION

This special issue of *Macroeconomic Dynamics* is devoted to papers that address various measurement problems while drawing on economic theory in a manner that is theoretically internally consistent at all relevant levels of aggregation and in relation to the models within which the measured data are used. The special issue is part of a larger initiative to promote measurement with theory, as opposed to the well-known measurement without theory and theory without measurement. The eight papers in this special issue can be grouped into three general classes:

Papers that address some of the problems associated with making international comparisons of welfare and productivity;
Papers that draw primarily on production theory; and
Papers that draw primarily on consumer theory.

Of course, some papers could be slotted into more than one of the above categories; in particular, the first two papers in the international comparisons category draw on consumer theory, whereas the third paper in this category draws on production theory. The second paper in the production theory category uses both

Address correspondence to: William A. Barnett, Department of Economics, University of Kansas, Snow Hall, 1460 Jayhawks Blvd., Lawrence, KS 66045-7585, USA; e-mail: barnett@ku.edu.

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consumer theory regarding occupational choice and producer theory regarding financial intermediation.

Sections 2, 3, and 4 will be devoted to brief descriptions of the papers that appear in each of these three categories.

2. INTERNATIONAL COMPARISONS OF PRICES, QUANTITIES, AND PRODUCTIVITY

Three papers in this special issue make international comparisons. The first paper is by Robert Feenstra, Hong Ma, and Prasada Rao (2009; henceforth FMR). Their paper addresses the following problem. Suppose the World Bank or some other organization undertakes periodic comparisons of final demand prices every 5 or 10 years so that estimates of real GDP and its components can be made across countries for the year when the International Comparison Project (ICP) constructs its price estimates. Then national price and expenditure data can be used to construct comparable estimates of real GDP across time and countries. The problem with these comparisons is that they change (sometimes very dramatically) every time a new cross-sectional comparison is made; that is, the resulting panel data are not consistent across time and space. TFMR provides a solution to this problem by extending the methodology developed by Neary (2004), who makes a single cross-sectional comparison to the case where there are two sets of cross-sectional data.

To explain the FMR methodology, it will be useful to explain Neary's methodology first. Neary (2004) draws on an early method for making international comparisons that was suggested by Geary (1958).[1] Because Neary's method for making international comparisons is a modification of Geary's method, we will explain Geary's method first.

Suppose we have data on the prices for some time period (in national currencies but in comparable units of measurement) for N commodity groups and J countries, $p_j \equiv [p_{j1}, \ldots, p_{jN}]$, where p_j is the country j price vector and $q_j \equiv [q_{j1}, \ldots, q_{jN}]$ is the corresponding country j quantity vector for $j = 1, \ldots, J$. Thus total expenditure on these commodities for country j in the time period under consideration is the inner product of the country j price and quantity vectors, which we denote by $p_j \cdot q_j$ for $j = 1, \ldots, J$. The Geary–Khamis or GK vector of *international reference prices* is the vector $\pi \equiv [\pi_1, \ldots, \pi_N]$ and the vector of *true exchange rates*[2] is the vector $\varepsilon \equiv [\varepsilon_1, \ldots, \varepsilon_J]$. The components of these two vectors are the solution to the following set of equations:[3]

$$\pi_n = \sum_{j=1}^{J} \varepsilon_j p_{jn} q_{jn} / \sum_{j=1}^{J} q_{jn}; \quad n = 1, \ldots, N; \tag{1}$$

$$\varepsilon_j = \pi \cdot q_j / p_j \cdot q_j; \quad j = 1, \ldots, J. \tag{2}$$

Once the reference prices π have been determined, the GK *quantity aggregates*, Q_j for $j = 1, \ldots, J$, are defined as the inner product of the international price

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vector π and the country j quantity vector, q_j; that is, we have

$$Q_j \equiv \pi \cdot q_j; \quad j = 1, \ldots, J. \tag{3}$$

Neary's modification of Geary's method works as follows. First, Neary restricted himself to making comparisons of consumption across countries, and so consumer theory can be applied to these comparisons. Second, Neary assumed that per capita consumption data across countries can be rationalized by assuming common (nonhomothetic) tastes across countries.[4] Thus using the per capita consumption data for 11 commodity groups for 60 countries for the year 1980 that were constructed by the International Comparisons Project (ICP), Neary estimated a flexible functional form $e(p, u)$ for a consumer expenditure function.[5] Once the expenditure function has been estimated, country utility levels u_j can be calculated by solving the following equations for u_j:

$$e(p_j, u_j) = p_j \cdot q_j; \quad j = 1, \ldots, J. \tag{4}$$

Given that the expenditure function e is known and the country utility levels u_j have been determined via equations (4), we could choose any reference price vector π and use money metric utility[6] estimates $U_j(\pi)$ to obtain a theoretically consistent *cardinal measure of the per capita consumption of country j in real terms*:

$$U_j(\pi) \equiv e(\pi, u_j); \quad j = 1, \ldots, J. \tag{5}$$

The family of cardinal utility measures defined by (5) is very closely related to the family of *Allen* (1949) *quantity indices* of per capita consumption between countries j and k:

$$Q_A(\pi, u_j, u_k) \equiv e(\pi, u_k)/e(\pi, u_j); \quad j, k = 1, \ldots, J. \tag{6}$$

Thus, for each choice of a reference price vector π, one can define consistent measures of the per capita consumption of countries in the cross-sectional comparison using (5). and the Allen indices defined by (6) simply take ratios of the cardinal measures defined by (5).

Basically, Neary (2004) used the per capita measures defined by (5) (or a normalization of these measures) to rank the per capita consumption expenditures of the 60 countries in his 1980 sample of countries. However, we now encounter the interesting problem of how exactly the international vector of reference prices π should be chosen.

Neary used the π solution to the following equations, which are related to the original Geary equations, (1) and (2):[7]

$$\pi_n = \sum_{j=1}^{J} \varepsilon_j p_{jn} q_{jn} / \sum_{j=1}^{J} \partial e(\pi, u_j)/\partial \pi_n; \quad n = 1, \ldots, N; \tag{7}$$

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$$\varepsilon_j = e(\pi, u_j)/p_j \cdot q_j; \quad j = 1, \ldots, J$$
$$= e(\pi, u_j)/e(p_j, u_j). \tag{8}$$

Once the vector of Neary international reference prices π has been determined by solving (7) and (8), consistent theoretical measures of country real consumption per capita, $U_j(\pi)$, can be obtained by using the estimated expenditure function e and definition (5) for this π. Neary (2004, p. 1417) called his real consumption estimates *Geary–Allen true indices of real income* and he termed his overall multilateral method for making international comparisons the *Geary–Allen international accounts* (GAIA). Because multilateral methods are usually named after the pioneers who invented the method and established the properties of the method, it seems appropriate to call Neary's multilateral method the Geary–Neary (GN) method.

Now we are in a position to evaluate the contribution of FMR. They too estimated a nonhomothetic flexible functional form for an expenditure function (the AIDS model), but they used the per capita expenditure data pertaining to *two* ICP price and quantity comparisons: the comparisons for 1980 and for 1996. They used Neary's data and commodity classification for 1980 and aggregated the ICP data for the 1996 round of international comparisons to match Neary's commodity classification. They ended up with a consistent data set for 48 countries[8] that appeared in both the 1980 and 1996 data sets. Once the AIDS expenditure function was estimated, FMR used the methodology illustrated by equations (4) and (5) to construct estimates of real consumption per capita for 48 countries for the years 1980 and 1996; that is, they succeeded in their goal of obtaining consistent international comparisons of per capita "income" over time and space.

FMR also raise some interesting issues that have not been discussed in the literature, which are centered on Neary's nonhomothetic estimation methodology, such as: What are the right reference prices π to use in equations (5), which provide cardinal estimates of per capita consumption? Neary simply assumed that his GAIA reference prices constructed by solving equations (7) and (8) were the right reference prices and did not discuss the arbitrariness inherent in this choice. FMR experiment with alternative choices for the reference prices π. Three of their choices are Neary's GAIA reference prices, U.S. prices,[9] and the unweighted geometric mean of all 96 (48 countries times 2 observations) country prices. Of course, the ordinal ranking of per capita consumption across countries should not depend on the choice of π, but the results tabulated in the paper by FMR show that the cardinal ranking of country observations does change considerably as π changes. The fact that the cardinal estimates of per capita consumption change considerably as π changes means that it is necessary to debate what the "right" choice of π is. From the viewpoint of any single country j, the most meaningful choice of π would be p_j, country j's price vector. However, in the present context, we have *two* country j price vectors, say p_j^1 and p_j^2, representing the country j price vectors for 1980 and 1996, respectively. One could argue that the 1996 price

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vector (or more generally the last price vector in the sample) is the preferred choice between p_j^1 and p_j^2, because comparing the relative size of country budget sets in the present will be easier to accomplish if the most current set of country prices are used in the per capita consumption comparisons defined by (5) above. One could also argue that it would be more appropriate to choose reference prices for the country under consideration that are *representative* of the structure of relative prices for the entire sample period, and this would lead us to set the preferred country j reference prices, $\pi_j \equiv [\pi_{j1}, \ldots, \pi_{jN}]$, equal to the geometric mean of the two country price vectors, $[(p_{j1}^1 p_{j1}^2)^{1/2}, \ldots, (p_{jN}^1 p_{jN}^2)^{1/2}]$.[10] When this choice π_j is used for π, *country j's preferred set of per capita real consumption estimates* can be defined as follows:

$$U_k^1(\pi_j) \equiv e(\pi_j, u_k^1);\ U_k^2(\pi_j) \equiv e(\pi_j, u_k^2); \quad k = 1, \ldots, J, \tag{9}$$

where u_k^t is country k's estimated utility level for year t, which results from the econometric estimation of the expenditure function e over the panel data set. Thus instead of a single set of cross-country comparisons, the above suggested methodology would lead to a *set* of J sets of cross-country comparisons, one for each country being compared.

Of course, for many purposes, a single ranking of per capita "incomes" is required and so, in the end, the J rankings defined by (9) will have to be averaged. Note that we are now in exactly the same situation that occurs when normal bilateral index number theory is applied in a multilateral context; that is, a superlative bilateral index number formula can be used to generate estimates of per capita consumption using country j as the base country, and this leads to J separate star rankings of real consumption. These separate measures are then averaged to obtain a final single ranking. The simplest way to average the individual star rankings is to take their equally weighted geometric average. If the superlative index number formula is the Fisher (1922) ideal quantity index,[11] then the resulting multilateral method is due to Gini (1931), and it is known as the EKS or GEKS multilateral method. Note that this method of weighting the separate star estimates is a *democratic* method of weighting; that is, each country gets the same weight in the geometric mean of the separate country estimates. It is also possible to weight according to the relative size of each country (this is known as *plutocratic* weighting[12]), but in the present context, democratic weighting seems more appropriate. FMR did not calculate the country-specific estimates of real per capita consumption defined by (9) or take the geometric average of these estimates, but we conjecture that this geometric average will generally be close to GEKS or Caves et al. (1982) estimates based on traditional multilateral index number theory (which does not use econometrics).

In addition to generalizing Neary's method to a panel data context, FMR have several other very interesting results. In particular, they show (for both AIDS and translog nonhomothetic preferences) how to generate Allen quantity indices of the type defined by (6) above easily for arbitrary reference price vectors π, using only

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information on the subset of parameters in these functional forms that are related to nonunitary income elasticities. These results should be of general interest to econometricians who estimate systems of consumer demand equations.

The second paper dealing with international comparisons in this special issue is by Robert Hill and Peter Hill (2009). Their paper explains the new methodology that was used in the 2005 International Comparison Program (ICP), which compared relative price levels and GDP levels across 146 countries.[13] In this round of the ICP, the world was divided into five regions: OECD and CIS countries, Africa, South America, Asia Pacific, and West Asia. What is new in this round compared to previous rounds of the ICP is that each region was allowed to develop its own product list and collect prices on this list for countries in the region. The regions were then linked using another separate product list, 18 countries across the five regions collected prices for products on this list, and this information was used to link prices and quantities across the regions. Hill and Hill provide a comprehensive review of the new methodology that was used in ICP 2005. Their methodological review covers three topics:

The construction of price indices at the basic heading level;
The construction of price indices between countries within one of the five regions; and
The linking of the country comparisons across regions.

Hill and Hill are well qualified to describe the new methodological developments in the ICP, because Peter Hill (2007) wrote all of the theory chapters in the World Bank's methodological handbook and Robert Hill (1997, 1999, 2001, 2004) has written numerous papers on multilateral index number theory.[14]

Hill and Hill look ahead to the next round of the ICP and make an interesting new methodological suggestion that is a variant of Robert Hill's (1999, 2001, 2004) minimum–spanning tree methodology for international comparisons. Based on a suggestion by Diewert, they suggest that countries could be broken up into two groups: those with well-funded statistical offices and those with less well-funded offices. The first group of countries would be labeled as core countries, and Hill's spanning-tree methodology would be applied initially to only the core countries.[15] The remaining countries would be linked to the initial core-country tree using an appropriate similarity measure for the structure of relative prices in each noncore country as compared to each country in the core group of countries. Thus, suppose that there are C countries in the core group of countries and N countries in the noncore group. Denote the vector of basic heading prices for a core country c by p^c for $c = 1, \ldots, C$ and for a noncore country n by P^n for $n = 1, \ldots, N$. Suppose further that a suitable measure of relative price dissimilarity, $s(p, P)$, has been chosen.[16] Let n be an arbitrary noncore country and consider the following minimization problem:

$$\min\{s(p^c, P^n): c = 1, \ldots, C\}. \tag{10}$$

Suppose that the core country $c(n)$ solves the above minimization problem, so that the structure of relative prices in $c(n)$ is the most similar to the structure of

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relative prices in the noncore country n.[17] Then we link country n to country $c(n)$ using a superlative index number formula, such as the Fisher (1922) ideal formula. Thus there are N simple minimization problems of the form (10) to be solved: one for each noncore country. When all of the problems have been solved, all of the noncore countries will be linked to the core-spanning tree. The resulting overall spanning tree will have the property that none of the noncore countries will have a large influence in the overall spanning tree (and noncore countries will be linked to core countries which have the most similar structure of relative prices).

The paper by Robert Inklaar and Marcel Timmer (2009) is our third paper that deals with international comparisons. However, this paper deals with comparison of industry levels of output, input, and productivity across countries rather than with comparisons of consumption or final demand, which were the focus of the first two papers.

The basic question that Inklaar and Timmer ask is whether productivity levels are converging across OECD countries over time. To address this question, the authors developed a new industry-level database for 20 OECD countries over the years 1970–2005. The authors combined the EU KLEMS growth accounting database with their GGDC productivity level database. This second database provides productivity level comparisons for 20 OECD countries at a detailed industry level for the benchmark year 1997. Then the EU KLEMS database was used to extrapolate this benchmark through time from 1970 to 2005. This was done at a detailed industry level. Modern production theory based on the user cost of capital and superlative indices was used in constructing their database.[18]

Inklaar and Timmer find that Bernard and Jones (1996) were basically right: patterns of convergence in a set of advanced OECD countries differ considerably across sectors. Inklaar and Timmer find a process of steady convergence in market services since the 1970s, but they find little evidence for convergence in manufacturing or other goods-producing industries. Moreover, when they analyze convergence at a more detailed industry level using a dataset of 24 industries, they find that the patterns of convergence and divergence since 1980 are very different and far from homogenous, even within industry groups such as market services.[19]

3. PRODUCTION THEORY

This special issue contains two papers relevant to measurement in a production context. The paper by Bert Balk (2009b) in this special issue looks at the relationship between measures of productivity growth that are based either on a *gross-output framework* or on a *value-added framework*. If Y^t denotes the aggregate output of a production unit in period t and X^t denotes the corresponding aggregate input used by that unit in period t, the period t (total factor) *productivity* (TFP) of the unit is simply the ratio Y^t/X^t. The corresponding period t TFP growth of the unit, TFPG^t, is defined as the ratio of the unit's period t TFP to the corresponding period $t-1$ TFP:

$$\text{TFPG}^t \equiv [Y^t/X^t]/[Y^{t-1}/X^{t-1}] = [Y^t/Y^{t-1}]/[X^t/X^{t-1}]. \qquad (11)$$

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The second expression in (11) indicates how TFP growth can be computed in practice: aggregate output growth Y^t/Y^{t-1} can be replaced by a bilateral quantity index, $Q(p^{t-1}, p^t, y^{t-1}, y^t)$, where p^t and y^t are the period t output price and quantity vectors for the production unit, and aggregate input growth, X^t/X^{t-1}, can be replaced by a bilateral quantity index, $Q^*(w^{t-1}, w^t, x^{t-1}, x^t)$, where w^t and x^t are the period t input price and quantity vectors for the production unit.[20] The difference between the gross-output and value-added approaches to measuring TFP growth can now be explained. In the gross-output framework, $Q(p^{t-1}, p^t, y^{t-1}, y^t)$ is an aggregate growth rate for all of the outputs produced by the production unit and $Q^*(w^{t-1}, w^t, x^{t-1}, x^t)$ is an aggregate growth rate for all of the primary and intermediate inputs used by the production unit, whereas in the value-added framework, $Q(p^{t-1}, p^t, y^{t-1}, y^t)$ is an aggregate growth rate for all of the outputs produced by the production unit *less* the intermediate inputs used by the unit[21] and $Q^*(w^{t-1}, w^t, x^{t-1}, x^t)$ is an aggregate growth rate for just the primary inputs used by the production unit. If revenues equal costs for the production unit in both periods, Balk is able to derive a very general exact relationship between the gross output and value added measures of TFP growth; see his Theorem 1. Balk sums up his result in words as follows: if the unit's profits are zero in both periods, then its value added–basedproductivity change is equal to its gross output–based productivity change times the ratio[22] of average revenue to average value added for the two periods under consideration. Thus the value-added measure of TFP growth will always be larger than the corresponding gross-output measure if profits are zero in both periods. Balk also provides an elegant proof of Domar's (1961) aggregation rule, which relates the gross-output TFP growth rates of a set of production units to an economy-wide measure of TFP growth.

In Section 4 of his paper, Balk turns his attention to *difference measures of TFP growth*. Because many readers will not be familiar with this approach, we will provide an introduction to this topic.[23]

Traditional bilateral index number theory decomposes a value ratio pertaining to the two periods under consideration (say periods 0 and 1) into the product of a price index, $P(p^0, p^1, q^0, q^1)$, and a quantity index, $Q(p^0, p^1, q^0, q^1)$; that is, we have

$$p^1 \cdot q^1/p^0 \cdot q^0 = P(p^0, p^1, q^0, q^1)Q(p^0, p^1, q^0, q^1). \tag{12}$$

If there is only one commodity in the aggregate, then the *price index* $P(p^0, p^1, q^0, q^1)$ collapses down to the single price ratio p_1^1/p_1^0 and the *quantity index* $Q(p^0, p^1, q^0, q^1)$ collapses down to the single quantity ratio q_1^1/q_1^0. Thus traditional index number theory is based on a *ratio* principle.

Bennet (1920) and Montgomery (1937) pursued the branch of index number theory where *differences* replaced the *ratios* in (12). Thus, they looked for two functions of $4N$ variables, $\Delta P(p^0, p^1, q^0, q^1)$ and $\Delta Q(p^0, p^1, q^0, q^1)$, which added up to the value *difference* in the aggregate rather than the value *ratio*; that

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is, these two functions were to satisfy the following equation:

$$p^1 \cdot q^1 - p^0 \cdot q^0 = \Delta P(p^0, p^1, q^0, q^1) + \Delta Q(p^0, p^1, q^0, q^1). \qquad (13)$$

The two functions $\Delta P(p^0, p^1, q^0, q^1)$ and $\Delta Q(p^0, p^1, q^0, q^1)$ are to satisfy certain tests or properties that will allow us to identify $\Delta P(p^0, p^1, q^0, q^1)$ as a *measure of aggregate price change* and $\Delta Q(p^0, p^1, q^0, q^1)$ as a *measure of aggregate quantity or volume change*. Note that if either of these functions is determined, then the other function is also determined. The terms *indicator* of price and quantity change are used to describe $\Delta P(p^0, p^1, q^0, q^1)$ and $\Delta Q(p^0, p^1, q^0, q^1)$ respectively[24] (as opposed to the terms price and quantity *index*, which appear in the traditional ratio approach to index number theory).

Where might one use the difference approach to analyzing value change? A natural home for this approach is in the business and accounting community. The usual ratio approach to the decomposition of value change is not one that the business and accounting community finds natural; a manager or owner of a firm is typically interested in analyzing profit *differences* rather than *ratios*. Thus interest centers on decomposing cost, revenue, or profit changes into *price* and *quantity* (or volume) *effects*, and this is precisely what Balk (2009b) does in Section 4 of his paper. Note that if (13) represents a profit decomposition for a production unit, then $\Delta Q(p^0, p^1, q^0, q^1)$ can be interpreted as a measure of *efficiency improvement* for that unit; that is, it is the difference counterpart to TFP growth in the usual ratio approach to index number theory.[25] For example, the owner of an oil exploration company will generally be interested in knowing how much of the difference between current period profits and previous period profits is due to a change in the price of crude oil [this will show up in the $\Delta P(p^0, p^1, q^0, q^1)$ term] and how much of the profit change is due to improvements in the operating efficiency of the company [the $\Delta Q(p^0, p^1, q^0, q^1)$ term].

Another natural application of the difference approach to index number theory is in *consumer surplus theory*. In this context, the problem is to decompose the change in a consumer's expenditures between two periods into a price-change component, $\Delta P(p^0, p^1, q^0, q^1)$, and a quantity change component, $\Delta Q(p^0, p^1, q^0, q^1)$, which can be interpreted as a constant-dollar measure of utility change. This line of research was started by Marshall (1890) and Bennet (1920) and continued by Hotelling(1938, 253–254), Hicks (1941–1942, 134; 1945–1946), and Harberger (1971). This second application of the difference approach to index number theory is pursued by Diewert and Mizobuchi (2009), and we will describe their contribution in more detail in the following section.

In Section 4 of his paper, Balk (2009b) establishes a remarkably simple result using the difference approach to describing the growth in efficiency of a production unit over the two periods under consideration: the value added–based TFP indicator of TFP growth is exactly equal to the corresponding gross output–based TFP indicator of TFP growth. Thus there is no need for Domar factors when the difference approach is used to measure the growth of efficiency!

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In Section 5 of his paper, Balk uses the continuous-time Divisia approach to the measurement of TFP growth (rather than discrete-time indices) and establishes essentially the same results that he established in Section 3; that is, under certain assumptions, he shows that value-added TFP growth is equal to the Domar factor times gross-output TFP growth.

In Section 6, Balk again uses a continuous-time framework, but in this section, he introduces a production function and assumes competitive cost-minimizing behavior on the part of the production unit, and he also assumes that the production unit maximizes value added, taking prices as fixed. He then looks at a cost function-based measure of technical progress and compares it to a value added function-based measure of technical progress. He again finds a Domar-type factor relating the two measures of technical progress. In the remainder of Section 6, Balk makes various assumptions about competitive behavior and the structure of technical progress in order to obtain generalizations of the results of Solow (1957), Jorgenson and Griliches (1967), and Denny et al. (1981) relating TFP growth (both gross output and value added) to (path-independent) measures of technical progress. Balk finds that path independence of the gross output–based TFP index requires that the technology exhibit Hicks input neutrality, whereas path independence of the value added–based TFP index requires Hicks value-added neutrality. In Balk's view, the two sets of assumptions on the structure of technology and the nature of technical progress are equally restrictive: they simply imply two numerically different measures of technological change. Balk notes that this state of affairs does not imply a breakdown of measurement, but it reflects a structural state of affairs. Technological change simply moves the production unit's production possibilities set through time. Measurement means that this movement must be mapped into one-dimensional space. There is no unique way to do this.

As has been emphasized by Barnett and Hahm (1994), Barnett and Zhou (1994), and Barnett et al. (1995), empirical research on financial intermediation that brings together production theory, index number theory, and econometrics in an internally coherent manner is rare. Considering the nature of the current financial crisis, few subjects can be considered as important as financial intermediation. Townsend and Urzua, in their innovative paper in this special issue, state (regarding contract theory models of financial intermediation and econometric policy evaluation) that "our goal in this paper is to bring these two strands of the literature together and discuss the assumptions that allow the researcher to go back and forth between the theory and the data." They consider the large literature on changes in financial policies that affect occupational choices by changing credit constraints and/or changing occupational choice risk conditions. As the authors state in the final sentence of their abstract, "all in all, our objective is to assess the impact of financial intermediation on occupational choices and income." In their paper, they consider, theoretically and with a number of empirical examples, various economic theories, econometric methods, and types of data that are useful in achieving their important objective. Because of the focus on occupational choice, this paper is at

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least as relevant to consumer theory as to production theory and admirably uses theory from both sides of the market.

4. CONSUMER THEORY

Three papers in this special issue look at various measurement problems that are associated with aspects of consumer theory. The first consumer theory paper, by Barnett and de Peretti (2009), deals with the subject that is logically prior to all other empirical applications in consumer theory: existence of aggregates and existence of sectors of the economy. Without existence of admissible clusterings of goods permitting aggregation over quantities and prices and separation of the economy into sectors to lower the dimensions of models, there are too many quantities and prices to permit empirical analysis with the typically small sample sizes available to economists. The admissibility condition permitting clustering together groups of goods as components of aggregates is blockwise weak separability. Although there is a long history of research on tests for weak separability, that hypothesis has been resistant to successful testing, as has been shown in Monte Carlo studies, starting with Barnett and Choi (1989).

Weak separability is equivalent to the existence of a composite function structure, a subtle hypothesis that is difficult to test by parametric means. Although flexible function-form specifications have been successful in testing many other hypotheses on functional structure, the imposition of blockwise weak separability on parsimonious flexible functional forms, such as the translog and generalized Leontief, results in loss of flexibility, often to a severe degree, as first shown by Blackorby et al. (1977).[26] Consequently, tests of weak separability become tests of the joint hypothesis of weak separability and a very inflexible aggregator function, with the latter subhypothesis being the most likely source of rejection. Other parametric approaches to testing weak separability have been proposed and used, but none so far have been shown to perform well in Monte Carlo studies.

The inherent problems associated with parametric testing of weak separability have resulted in the growth of nonparametric approaches, often based upon revealed preference theory, with the seminal papers being those of Varian (1982, 1983), who drew on the earlier work of Afriat (1967) and Diewert (1973). But these tests have similarly performed poorly in Monte Carlo studies, because they have tended to be deterministic tests that do not cope well with violations of revealed preference theory resulting from noise in the data.

In their paper, Barnett and Peretti introduce seminonparametric testing into this literature. This middle-ground approach between parametric and nonparametric approaches solves the problems associated with the earlier approaches. Barnett and Peretti's seminonparametric approach is fully stochastic and is not inflexible under the null. Hence their approach is a direct test of weak separability rather than a composite test embedding a more restrictive hypothesis within the null. By eliminating the bias against acceptance of weak separability inherent in the earlier

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approaches, Barnett and Peretti's seminonparametric test performs well in Monte Carlo testing.

The second consumer theory paper is by Erwin Diewert and Hideyuki Mizobuchi (2009), and it addresses the problem of finding index number formulae (and indicator formulae) that are exact for flexible functional forms for nonhomothetic preferences. Diewert (1976) addressed this problem in the index number context, but his exact index number results assumed that the consumer had homothetic preferences for the most part.[27] Diewert (1992a) also addressed the problem of finding exact indicator formulae in the difference approach to index number theory, but in the end, his results followed the example of Weitzman (1988), who assumed that preferences were homothetic. Thus the problem of obtaining indicator formulae that are exact for nonhomothetic preferences remains open. This is the problem that Diewert and Mizobuchi address.

As noted earlier, traditional index number theory is based on ratio concepts. Thus, if the consumer's preferences are homothetic (so that they can be represented by a linearly homogeneous utility function), then the family of Konüs (1939) price indices collapses to a ratio of unit cost functions and the family of Allen (1949) quantity indices collapses to a ratio of utility functions, where these functions are evaluated with the data of, say, period 1 in the numerator and the data of period 0 in the denominator. After describing this traditional approach to index number theory, Diewert and Mizobuchi switch to the economic approach pioneered by Hicks (1941–1942, 1945–1946), which is based on differences. As noted in our discussion of Balk's paper, in the traditional approach to index number theory, a value ratio is decomposed into the product of a price index and a quantity index, whereas in the difference approach, a value difference is decomposed into the sum of a price indicator (which is a measure of aggregate price change) and a quantity indicator (which is a measure of aggregate quantity change). The difference analogue to a theoretical Konüs price index is a *Hicksian price variation*, and the difference analogue to an Allen quantity index is a *Hicksian quantity variation*, such as the equivalent or compensating variation. For normal index number theory, the theoretical Konüs and Allen indices are defined using ratios of cost functions, but in the difference approach to index number theory, the theoretical price and quantity variation functions are defined in terms of differences of cost functions. Both index number formulae and indicator functions are known functions of the price and quantity data pertaining to the two periods under consideration.

Diewert and Mizobuchi define a given price or quantity indicator function to be *strongly superlative* if it is exactly equal to a corresponding theoretical price or quantity variation, under the assumption that the consumer has (general) preferences that are dual to a flexible cost function that is subject to money metric utility scaling. As we noted in our discussion of FMR, the term "money metric utility scaling" is due to Samuelson (1974), and it is simply a convenient way of cardinalizing a utility function. Diewert and Mizobuchi show that the Bennet (1920) indicator functions are strongly superlative. Their results require that the consumer's preferences be represented by a certain translation-homothetic cost

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function that is a variant of the normalized quadratic cost function introduced by Diewert and Wales (1987).

Diewert and Mizobuchi also show that the aggregation-over-consumers problem in the difference approach to index number theory is not as difficult as it is in the ratio approach to index number theory. In particular, Diewert and Mizobuchi show that it is possible to measure the arithmetic average of the economy's sum of the individual household equivalent and compensating variations exactly using only aggregate data, because this aggregate measure of welfare change is exactly equal to the Bennet quantity indicator using only aggregate quantity data. In other words, the difference approach to the measurement of aggregate price and quantity change has better aggregation properties than the traditional ratio approach.

Diewert and Mizobuchi also provide an economic interpretation for each term in the sum of terms that make up the Bennet price and quantity indicators. The decomposition results developed here are analogues to similar results obtained by Diewert and Morrison (1986) and Kohli (1990) in the traditional approach to index number theory.

Diewert and Mizobuchi conclude their paper by using the difference approach to measure aggregate Japanese consumption, and they contrast their results with the results generated by the traditional ratio approach to the measurement of real consumption.

The third paper dealing with measurement problems in the context of consumer theory is by W. A. Barnett, M. Chauvet, and H. L. R. Tierney (2009). Most of the papers in this special issue connect together measurement and theory through the use and advancement of economic index number theory and microeconomic aggregation theory. But there is another tradition that has been growing in importance: the use of state-space econometric modeling with measurement functions. In this paper, Barnett et al. integrate the state-space time-series approach with the economic index number–theoretic approach using the state-space approach to demonstrate that the aggregation-theoretic Divisia monetary aggregates deviate from their common dynamics with the official atheoretical simple-sum monetary aggregates in ways that have predictive power regarding turning points in the business cycle.

Their state space approach uses a factor model with regime switching. The model separates out the common movements underlying the theoretical and atheoretical monetary aggregate indices, summarized in the dynamic factor, from individual variations in each individual series, captured by the idiosyncratic terms. The idiosyncratic terms and the measurement errors reveal where the monetary indices differ.

In future research, it could be useful to generalize to explicit treatment of measurement error of component quantities and prices and to incorporate of the Divisia monetary growth–rate variances introduced by Barnett and Serletis (1990) to measure dispersion of growth rates over components of aggregates. In fact, the approaches used in all of the papers in this special issue could benefit from more explicit treatment of second moments and the consequent possible sources

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of error in index number theory with data that are potentially subject to errors in the variables.

NOTES

1. For surveys of the early methods used to make international comparisons that rely on index number theory, see Diewert (1988, 1999) and Balk (1996). In this literature, Geary's method is known as the Geary (1958)–Khamis (1972) method (the GK method) because Khamis provided a rigorous proof of the existence of a solution to Geary's equations.

2. Neary (2004, p. 1413) uses this terminology. In the international comparisons literature, the country j's true exchange rate ε_j is usually replaced by its reciprocal, the country j's purchasing power parity.

3. The system of equations (1) and (2) only determines π and ε up to a positive scalar multiple. Thus we need an additional normalization on (1) and (2) such as $\varepsilon_1 = 1$ or $\pi_1 = 1$ to obtain a unique solution.

4. Thus p_j is now a vector of consumer prices for country j and q_j is the corresponding per capita consumption vector.

5. Neary (2004, p. 1420) estimated both the AIDS model of Deaton and Muellbauer (1980) and the more flexible QUAIDS model of Banks et al. (1997). Neary (2004, p. 1422) noted that his AIDS and QUAIDS models were visually indistinguishable in his Figure 1.

6. This terminology is due to Samuelson (1974, p. 1262), but the basic idea is due to Hicks (1941–1942). Basically, this method cardinalizes utility using the distance from the origin of a family of parallel budget hyperplanes (indexed by the reference price vector) where each budget hyperplane is just tangent to an indifference surface.

7. As in the GK system of equations, Neary shows that one additional normalization on the components of π and ε is needed to obtain a unique solution to (7) and (8).

8. Their analysis does rest on the assumption that the commodity units in the two ICP rounds are comparable, an assumption that is only approximately correct.

9. The components of the U.S. π are the geometric means of the 1980 and 1996 U.S. prices for each of the 11 components of consumption.

10. FMR use this set of country reference prices as building blocks in some of their comparisons.

11. Caves et al. (1982) applied this method using the Törnqvist–Theil bilateral quantity index as their bilateral index.

12. See Diewert (1988, p. 71; 1999), who introduced this terminology in the multilateral context.

13. The 2005 ICP round was sponsored by the World Bank and other national and international statistical agencies. The final results of this round of GDP comparisons were released in February, 2008; see the World Bank (2008). The various ICP rounds play a very important role in the construction of the Penn World Tables, which are heavily utilized by many development and macro economists.

14. The World Bank's (2008) release of the ICP 2005 results did not describe the methodology used in the comparison. The theoretical chapters in the World Bank's Handbook written by Peter Hill (2007) did not describe all of the methodology actually used in the final comparison. Hence the paper by Hill and Hill is particularly valuable in describing the actual methodology used in some of the problem areas. For additional methodological material on ICP 2005, see Diewert (2008) and Deaton and Heston (2008).

15. Alternatively, the initial set of core country comparisons could be obtained using the GEKS method.

16. If p is proportional to P, then $s(p, P) = 0$, and if p is not proportional to P, then $s(p, P) > 0$. Thus the dissimilarity measure is analogous to a distance function in the mathematics literature. For additional material on the properties of dissimilarity measures, see Diewert (2009).

17. If more than one country c is a solution to (10), then any of these solution countries could be taken as the link of country n to the core-spanning tree. Alternatively, all of the solution countries

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could be used as links to the core-spanning tree and a geometric average of the resulting links could be taken.

18. This literature dates back to the pioneering contributions of Jorgenson and Griliches (1967). Later, their continuous-time methodology using Divisia indices was adapted to discrete time and the use of superlative indexes by Diewert (1976), Caves et al. (1982), and Diewert and Morrison (1986).

19. One limitation of their analysis should be kept in mind: the EUKLEMS database does not have the services of land or inventories included as inputs. Thus results for land-intensive sectors such as agriculture or for inventory-intensive sectors such as retailing may be less reliable than results for other sectors.

20. For additional material on basic productivity analysis, see Jorgenson and Griliches (1967), Diewert (1992b), Balk (2003), and Diewert and Nakamura (2003).

21. In the value-added framework, the vector y^t consists of all of the outputs produced by the unit during period t as well as all of the intermediate inputs used during the period. The components of y^t that correspond to outputs are given positive signs, whereas the components of y^t that correspond to intermediate inputs are given negative signs.

22. Balk calls this ratio the Domar factor; see Domar (1961).

23. This topic is pursued in much greater depth by Diewert (1992a, 2005) and Balk (2009a).

24. This indicator terminology was introduced by Diewert (1992a; 2005, 349).

25. See Diewert (2005, 353) for this interpretation of $\Delta Q(p^0, p^1, q^0, q^1)$. However, the basic idea can be traced back to the early accounting and industrial engineering literature; see Harrison (1918, 275).

26. However, Diewert and Wales (1995) derived tests for homogeneous weak separability in the production context, using the normalized quadratic functional form, that were not subject to this inflexibility problem. For a survey of much of the relevant literature in a demand context, see Barnett and Serletis (2008).

27. Diewert (1976, 122–123) did establish two exact results for translog nonhomothetic preferences.

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