Testing Aggregation Consistency Across Geography and Commodities

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Abstract:

Consistent aggregation of production data across commodities and states was tested using Lewbel's generalized composite commodity theorem (GCCT). This was the first empirical GCCT test for consistent geographic aggregation and was applied to two groups of states. Consistent commodity aggregation was tested in all states for two output groups and three input groups and in one state for a larger number of groups. Using a more powerful test procedure than previously applied to production data, most tests for commodity aggregation gave ambiguous results. Consistent geographic aggregation was generally supported across Pacific Northwest states but was ambiguous across all Western states.

Key words: Aggregation, commodity, geographic, composite commodity theorem, multiple-comparison tests.

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Introduction

Issues related to aggregation consistency are often of great concern to researchers since aggregate data are widely used in economic analyses. Because they frequently conduct economic analysis and draw inferences using aggregate data and models, it is important to know whether behavioral properties applied to disaggregate relationships can be applied to aggregate relationships.

Many studies on consistent aggregation focus on theoretical conditions under which individual economic laws (e.g. law of demand) can be applied to aggregate data (e.g., Hicks 1936, Leontief 1936, 1947, Gorman 1959, Barnett 1979, Stoker 1984, Chambers and Pope 1996, Lewbel 1996). These studies have derived conditions under which aggregate models reflect and provide interpretable information about the underlying behavior of disaggregate units (commodities, individuals, or firms). Others have constructed consistent aggregation conditions over individual consumers and producers and derived functional forms for utility (or expenditure) equations of aggregate demand or supply (Gorman 1953, Muellbauer 1975, Lau 1977, Russell 1982). Some of the literature is also concerned with the problems of choosing between aggregate and disaggregate models (Pesaran, Pierse, and Kumar 1989). Meaningful aggregate prediction and accurate aggregate parameter estimation are among the main objectives of researchers on these topics (Shumway and Davis 2001).

Preference for using aggregate rather than individual agent data in analysis is based on several factors. Under some circumstances, individual agent data can be more costly to collect than aggregate data. Deriving aggregate inferences is more straightforward when aggregate data are used. Aggregate data may simplify economic modeling since “aggregate models can often be estimated using more robust functional forms” (Hellerstein 1995, p.623). Consistent multi-stage choice and representative-agent analysis is possible with data consistently aggregated across commodities or firms.

Although use of aggregate data has many benefits, aggregate models can lead to spurious parameter estimates when consistent aggregation conditions are not satisfied (Williams and Shumway 1998a). Spurious parameter estimates lead in turn to unreliable policy inferences derived from them. Consequently, empirical testing for consistent aggregation has become an important issue in economic analysis. However, most studies that test for consistent aggregation conditions focus on commodity-wise aggregation and ignore aggregation consistency across firms, individuals or geography (Shumway and Davis 2001).

Consistency of commodity-wise aggregation is assured by any of four sufficient conditions: Hicks composite commodity theorem, Leontief composite commodity theorem, separability of production or utility function, or generalized composite commodity theorem. The Hicks composite commodity theorem requires that all prices of individual commodities in the group always move in fixed proportions. The Leontief composite commodity theorem is satisfied when quantity ratios of all individual commodities in the group move in exact proportion. While easy to test, these two conditions are almost never satisfied in real world data sets. Most empirical testing has focused on the third condition. Both parametric and nonparametric tests of separability have been conducted on many agricultural production data sets (e.g., Weaver 1977, Ray 1982, Shumway 1983, Capalbo and Denny 1986, Chavas and Cox 1988, Ball 1988, Lim and Shumway 1992a, Sckokai and Moro 1996, Williams and Shumway 1998a, 1998b).

The fourth sufficient condition, the generalized composite commodity theorem (GCCT), was discovered only recently (Lewbel 1996). The GCCT relaxes the conditions of the Hicks composite commodity theorem by allowing price ratios to vary over the data set as long as the distribution of the ratio of individual prices to their group price is independent of the distribution of group prices. It has the important advantage of imposing no restrictions on technology or utility. Although of very recent origin, the GCCT has been used to test for consistency aggregation of food consumption goods (Eales, Hyde, and Schrader 1998, Asche, Bremnes, and Wessells 1999, Blundell and Robin 2000, Karagiannis and Mergos 2002) and agricultural production outputs (Davis, Lin, and Shumway 2000).

Sufficient technology conditions for both linear and nonlinear aggregation across firms were identified by Chambers (1988). In the case of linear aggregation of output across firms, aggregation consistency requires that each firm-level marginal cost equals aggregate marginal cost. Its sufficient long-run condition is very restrictive -- identical constant-returns technologies. While nonlinear aggregation of output across firms does not require identical marginal costs, it also carries highly restrictive conditions. The sufficient condition is a quasi-homothetic cost function, which is implied by a transform of the same linearly homogeneous function. This restriction means that input requirement sets are parallel across firms.

In their aggregation survey of agricultural economics literature, Shumway and Davis (2001) identified 22 empirical studies that tested for consistent aggregation of food and/or agricultural commodities. Twenty tested for consistent commodity-wise aggregation, one tested for consistent geographic aggregation (based on firm-wise aggregation conditions but using state-level data), and one tested for both. These studies collectively reported nearly 1,500 tests for consistent commodity-wise aggregation but fewer than a dozen tests for consistent geographic aggregation. It is very possible that the highly restrictive nature of the sufficient technology conditions for consistent firm-wise aggregation have caused analysts to bypass testing because of the high likelihood they would not be satisfied by the data. Indeed, both studies rejected every consistent geographic aggregation hypothesis tested, even for pairs of states.

The GCCT has been developed and applied only as a test for consistent commodity-wise aggregation. However, a passing remark by Lewbel (1992) in an earlier paper suggested the possibility that the concept could also provide a sufficient condition for consistent agent (e.g., firm or geographic) aggregation. One of the objectives of this paper is to demonstrate that additional applicability of the GCCT. The second objective is to apply the GCCT in tests both for consistent aggregation of outputs and inputs in each of the 11 Western states and for consistent geographic aggregation across the three Pacific Northwest states and the 11 Western states.

The applicability of the GCCT for consistent firm-wise aggregation is demonstrated in the next section. It is followed in sequence by the test procedures, data and aggregate groupings, and the empirical results. The final section concludes.

Theoretical Overview

Lewbel (1996) developed the GCCT and proved that it is a sufficient condition for consistent commodity-wise aggregation within a demand context. Davis, Lin and Shumway (2000) demonstrated that the GCCT could be used to test for consistent commodity-wise aggregation within a supply (production) context. Because this paper is concerned about consistent aggregation across commodities and across geography, the applicability of the GCCT for firm-wise aggregation must be documented. It turns out to be a straightforward extension of the cited proofs for commodity-wise aggregation. However, the logic for expecting heterogeneous prices must be established first. It is followed by an abbreviated proof.

One consequence of perfect competition in simplified markets is that all firms should face the same set of prices. If they do, then all prices would be perfectly correlated and the Hicks composite commodity theorem would be satisfied. This would give theoretical justification for consistent aggregation across firms. However, even in competitive industries, heterogeneous prices actually exist across price-taking firms. Price heterogeneity may be due to differences in transportation, search costs, and/or human capital as well as incomplete markets under uncertainty and risk neutrality (Pope and Chambers 1989, Chambers and Pope 1996).

Given that heterogeneous prices do exist across price-taking firms, documentation is required that the GCCT is a sufficient condition for consistent firm-wise aggregation. The following is adapted from Lewbel's (1996) and Davis, Lin and Shumway's (2000) proofs for consistent commodity-wise aggregation.

Let p_i and x_i be the price and quantity, respectively, of a netput (x is positive if an output and negative if an input) of the i^{th} individual firm (i = 1,2, … n). Let s_i be the netput revenue or cost share for firm i, i.e., $p_i x_i / \Sigma_i p_i x_i$, where Σ_i sums over all firms. Taking the logarithm of the firm's price, $r_i = \log (p_i)$, **s** and **r** denote vectors of s_i and r_i, respectively, I identifies a subset (or group) of firms, P_I is the group price index that depends on all individual prices in the group I, and R_I is the logarithm of the group price index. Let $S_I = \Sigma_{i \in I} s_i$ denote a group's netput revenue or cost share. Comparable to the notation for individual firms, **S** and **R** are vectors of S_I and R_I. Also, $\rho_i = \log(p_i/P_I)$ is the logarithm of the ratio of firm i's price to the group's price, and $\boldsymbol{\rho}$ is the vector of the ratios.

Let $g_i(\mathbf{r})$ denote the theoretical netput share function for firm i specified as a function of the firm-level logarithmic price vector. Appending a random error term, e_i, with conditional expectation zero, the firm's share function is fully specified as $s_i = g_i(\mathbf{r}) + e_i$. The error term assumption, $E(e_i|\mathbf{r}) = 0$, implies $g_i(\mathbf{r}) = E(s_i|\mathbf{r})$, so the conditional expectation of the individual firm's netput share is equal to the theoretical netput share function. We can also define a group netput share (S_I) function similarly: $S_I = G_I(\mathbf{R}) + \varepsilon_I$, $E(\varepsilon_I|\mathbf{R}) = 0$, where $G_I(\mathbf{R})$ is the group's theoretical netput share function specified in terms of the vector of group logarithmic price indices $\mathbf{R}$. Also, $E(\varepsilon_I|\mathbf{R}) = 0$ implies $E(S_I|\mathbf{R}) = E(\Sigma_{i\in I} s_i|\mathbf{R}) = G_I(\mathbf{R})$, which means the conditional expectation of the group netput share is equal to the theoretical netput share function. Following Lewbel we define $G_I^*(\mathbf{r}) = \Sigma_{i\in I}\, g_i(\mathbf{r})$ in which G_I^* is the group's theoretical netput share function expressed as a function of the vector of firm-level logarithmic prices.

Two conditions are necessary to satisfy Lewbel's GCCT theorem. One is that demand functions are rational. The other is that the distribution of the vector ρ (the vector of the logarithm of the ratios of individual's price to the group's price) is independent of the distribution of the group logarithmic price vector $\mathbf{R}$. When both of these conditions hold, the adding up and homogeneity properties of individual consumer demand share functions are retained by the group share functions. The symmetry and negative semidefinite conditions also hold if the Hessian matrix $H(\mathbf{R}, z)$ is symmetric and $H(\mathbf{R}, z) + \widetilde{H}(\mathbf{R}, z)$ is negative semidefinite (Lewbel, 1996), where $H(\mathbf{R},z)$ is the square matrix having elements $H_{IJ}(\mathbf{R}, z)$, $H_{IJ}(\mathbf{R}, z) = \mathrm{cov}[\partial G_I^*(\mathbf{R}^*+\rho, z)/\partial z), G_J^*(\mathbf{R}^*+\rho, z) \mid \mathbf{R}, z]$, in which G_I^* are the group demand functions, $\widetilde{H}(\mathbf{R}, z)$ is the matrix of elements $\widetilde{H}_{IJ}(\mathbf{R}, z) = \mathrm{cov}[G_I^*(\mathbf{R}^* + \rho, z), G_J^*(\mathbf{R}^*+\rho, z) \mid \mathbf{R}, z]$, and z is the log of total consumption expenditure.

Similarly, in the case of firm-wise aggregation in the production context, the first condition is that all individual netput share functions $g_i(\mathbf{r})$ are rational. This means they are consistent with profit maximizing behavior. The second condition is that the distribution of the vector of relative prices ρ is independent of the group logarithmic price vector **R**. Following Lewbel's logic, let $\mathbf{R}^* = \mathbf{r} - \rho$ and substitute this equation into $G_I^*(\mathbf{r})$. $F(\rho)$ is denoted as the distribution function of ρ, and the following equation can be derived by integrating over this distribution:

$$(1)\ \int G_I^*(\mathbf{R}^* + \rho)dF(\rho) = E[G_I^*(\mathbf{R}^* + \rho)|\mathbf{R}] = G_I(\mathbf{R}).$$

This equation means that the group netput share function $G_I(\mathbf{R})$ is equal to the conditional expectation of the sum over individual netput share equations $G_I^*(\mathbf{r})$ (Davis, Lin and Shumway, 2000). This result holds whether the grouping is across commodities or across firms or other agents as long as the share is specified with respect to the selected group.

Consequently, the theoretical properties of individual netput share functions (adding up, homogeneity, symmetry, and positive semidefiniteness) are retained in group netput share functions $G_I(\mathbf{R})$ when the two conditions hold (see Davis, Lin and Shumway 2000, appendix for proof of homogeneity and symmetry). Lim and Shumway (1992) conducted nonparametric tests of the joint hypothesis of profit maximization, convex technology, and nonregressive technical change for agricultural production in each of the contiguous 48 states in the U.S. They failed to reject the joint hypothesis in any state. Therefore, given that the hypothesis of profit maximization was not rejected for any geographic unit considered in this study, the remaining question to be resolved with regard to consistent aggregation is whether the second condition is satisfied. That will be addressed through empirical testing.

Test Procedures

The null hypothesis for the GCCT is that the distribution of the random vector **ρ** is independent of the vector **R**. Lewbel (1996) implemented a conceptually accurate testing procedure for independence based on the time series properties of each ρ_i and R_I. If both ρ_i and R_I were stationary, Spearman's rank correlation test was used to test for independence. If both ρ_i and R_I were nonstationary, a cointegration test was applied instead of a correlation test[1]. The absence of correlation between stationary series or cointegration between nonstationary series implied independence between the series. If one series was stationary and the other nonstationary, the correlation test was unreliable and the cointegration test was not needed since two series cannot be cointegrated if one is stationary and the other is nonstationary (Granger and Hallman, 1987). Therefore, no test of independence was required under such circumstances.

Davis, Lin and Shumway (2000) strengthened Lewbel's testing procedure in two ways. Because of the low power of unit root tests, Lewbel appropriately reversed null hypotheses and conducted tests both for the null of nonstationarity (Dickey and Fuller 1979) and the null of stationarity (Kwiatkowski et al. 1991). Although application of both tests leads to nine possible outcomes for the time series properties of ρ_i and R_I, Lewbel mentioned only four in his paper. Davis, Lin and Shumway identified the full set of outcomes possible from the time series property tests of ρ_i and R_I. They also implemented a family-wise test (Holm 1979) of the null hypothesis that each ρ_i is independent of of R_I for $i \in I$. Because all of Lewbel's individual test statistics were higher than the negative critical value for rejecting the null hypothesis, it is not clear whether he would have rejected the GCCT when one independence test was rejected or

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[1] As Lewbel points out, these tests are designed for testing linear dependencies. Since independence is not necessarily a linear relation, some nonlinear dependency may exist even though independence is not rejected by either of these two tests.

only when every independence test between ρ_i and R_I, $i \in I$, was rejected. In the first case, the probability of committing type I error with his procedure exceeds the selected alpha level and the GCCT could be rejected even though it is true. In the second case, the probability of committing type II error exceeds expectations. Since it is not possible to conduct a joint hypothesis test for the GCCT, a family-wise testing criterion is preferred to basing the test decision on a set of individual hypothesis tests for the necessary conditions.

One limitation of Lewbel's testing procedure that also applied to Davis, Lin, and Shumway's procedure was the maintained hypothesis that if no cointegration existed between ρ and $\mathbf{R}$ within a group (for $i \in I$), no cointegration existed across groups (for $i \notin I$). Because of this maintained hypothesis, they only tested whether each ρ_i was independent of its own group price index R_I for $i \in I$. Because independence of vectors ρ and $\mathbf{R}$ requires that each element of ρ should be independent of each element of $\mathbf{R}$, they only tested for the necessary and not the sufficient conditions of the GCCT. Davis (2002) identified and corrected this important weakness in Lewbel's testing procedures and also order-ranked family-wise tests based on the power of the test. He concluded that the Simes (1986) test was the most powerful and the Holm (1979) test the least powerful among four alternatives.

Based on the logic of Lewbel's GCCT testing procedure and the improvements proposed by Davis, Lin and Shumway (2000) and Davis (2002), we tested for consistency of both commodity-wise and state-wise (geographic) aggregation of agricultural production data by the following procedures.

First, the time series properties of each data series were examined following Lewbel and Davis, Lin, and Shumway (DLS) by means of the ADF (Dickey-Fuller 1979) and the KPSS (Kwiatkowski et al. 1991) tests. The ADF test is widely used to test for unit roots in time series.

Its null hypothesis is nonstationarity. The null hypothesis of the KPSS test is stationarity. The ADF test was generated for the data series X from the following regression,

$$(2)\ \Delta X_t = \delta + \beta X_{t-1} + \sum_{j=1}^{k} \phi_j \Delta X_t + e_t,$$

where the series X represents a relative price series (ρ_i) or a nominal or deflated group price series R_I, and k is the lag order at which the residual e_t became white noise. Following Lewbel and DLS, maximum k was set at 4. Equation (2) does not include a time trend term because an examination of the time series plots of every series revealed no evidence of a time trend in the first differences. The null hypothesis of a unit root was rejected when values of β were significantly different from zero at the 10 percent significance level using critical values calculated by Dickey and Fuller (1979).

Under the null hypothesis of trend stationarity, the KPSS test examines the time series under study rewritten as the sum of a deterministic trend, a random walk, and a stationary error (Kwiatkowski et al. 1991): $X_t = \xi t + r_t + \varepsilon_t$, where $r_t = r_{t-1} + u_t$ is a random walk, and u_t is iid (0, σ_u^2). Testing the null hypothesis of $\sigma_u^2 = 0$ corresponds to testing the null hypothesis of trend stationarity. The test statistic was computed by the following formula:

$$(3)\ \hat{\eta}_\tau = \eta_\tau / s^2(l) = T^{-2} \sum S_t^2 / s^2(l),$$

where T is the sample size, S_t is the partial sum process of the residuals, $\sum_{i=1}^{t} e_i$, t = 1,2,…,T, e_i is obtained by regressing X_t on a constant and a time trend, $s^2(l)$ is a consistent estimator of σ^2 (long-run variance) and is computed by:

$$(4)\ s^2(l) = T^{-1} \sum_{t=1}^{T} e_t^2 + 2T^{-1} \sum_{s=1}^{l} w(s,l) \sum_{t=s+1}^{T} e_t e_{t-s}\ ,$$

where $w(s, l) = 1 - s/(l + 1)$. As in Lewbel and DLS, the lag truncation parameter, l, was set at four. The null hypothesis of stationarity was rejected when the test statistic exceeded the critical value provided by Kwiatkowski et al. at the 10 percent significance level.

Second, based on the outcome of the two time series tests for each series, correlation and/or cointegration tests were applied following Davis, Lin, and Shumway (2000) to test for independence between two series (ρ_i and R_I). If both ρ_i and R_I were stationary by both ADF and KPSS tests, we used Spearman's rank correlation test to test the GCCT. If both ρ_i and R_I were nonstationary, we used a cointegration test. Since two series cannot be cointegrated if one is stationary and the other is nonstationary, independence was verified without applying any additional tests in that case (Granger and Hallman, 1987). If one series was indeterminate and the other was stationary, we applied a correlation test. Similarly, if one series was indeterminate while the other was nonstationary, we used a cointegration test. If both series were indeterminate, both correlation and cointegration tests were applied.

Third, following Davis (2000), tests of independence were conducted between each ρ_i, $i \in I$, and each series in **R** rather than just the series in R_I. This assures that the sufficient as well as the necessary conditions for the GCCT were subjected to empirical test.

Fourth, the multiple comparison (family-wise) test procedure used to draw independence conclusions also followed Davis (2002). We used the most powerful test procedure (Simes 1986) considered by Davis. It can be summarized as follows. Suppose there are n individual tests with the specified significance level, α. Let $p_{(1)}, \ldots, p_{(n)}$ be the ordered p-values for testing hypotheses $H_0 = \{H_{(1)}, \ldots, H_{(n)}\}$. H_0 is rejected if $p_{(j)} \leq j\alpha/n$. Applying this procedure to test the independence of every series ρ_i, $i \in I$, with all series in **R**, the null hypothesis is rejected when the p-value is less than the respective significance level. The P-value of each individual independence test is the key in implementing the Simes procedure. Since the Engle-Granger (1987) tests have nonstandard asymptotic distributions, we couldn't get the p-value of the cointegration test based on those traditional distribution functions. We computed the p-value of each cointegration test following Mackinnon (1994)[2] to calculate approximate asymptotic distribution functions for unit root tests.

Time series properties of the data were checked first. Stationarity and nonstationarity tests were applied to each relative price ρ_i and every nominal and deflated group price. Deflated group prices were calculated by dividing each output (input) group price by the price index for all outputs (inputs). Relative prices ρ_i remained unchanged after being deflated. To increase the power of the tests, the ADF test for nonstationarity and the KPSS test for stationarity were both conducted to check the time series properties of the data, and a 10 percent significance level was used as the rejection criterion.

In terms of the order of the consistent aggregation tests, consistent commodity-wise aggregation in each state was tested first. If the GCCT was not rejected unambiguously, consistent state-wise aggregation was then tested.

Data and Aggregate Groupings

Annual data for the period, 1960-1996, in 11 states of the Western U.S. were used in this study. The data source was Ball's (1999) state-level agricultural output and input series for the contiguous 48 states in the U.S. This data set includes price and quantity data for 26 individual inputs (25 for Washington) and 20-75 individual outputs for each of the 11 states.[3] Although the number of outputs varies considerably among states, virtually every Western state produces one

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[2] MacKinnon (1996) employed response surface regressions to calculate distribution functions for cointegration test statistics with finite sample size. The finite-sample distributions differ only modestly from the asymptotic ones for small numbers of variables such as we use.

[3] The number of outputs in each state are: Arizona – 34, California – 75, Colorado – 36, Idaho – 30, Montana – 20, Nevada – 22, New Mexico – 28, Oregon – 42, Utah – 29, Washington – 43, Wyoming – 21.

or more commodity within the broad categories of livestock, milk, poultry, feed grains, food grains, oilseeds, vegetables, fruits and nut crops.[4] Detailed input data cover the broad categories of labor, capital, land, chemicals, energy, and materials.[5]

Grouping hypotheses for consistent commodity-wise aggregation and state-wise aggregation were based on previous empirical applications. For example, output is often aggregated into two or more groups and inputs into three or more categories. In this study, consistent aggregation tests were conducted in all states for outputs grouped into two hypothesized aggregate categories (livestock and crops) and inputs grouped into three hypothesized aggregate input categories (labor, capital, and materials).[6] To test state-wise aggregation consistency, two western regions were hypothesized: (1) Pacific Northwest, including Washington (WA), Idaho (ID), and Oregon (OR), and (2) Western States, including California (CA), Arizona (AZ), Nevada (NV), Utah (UT), Montana (MT), Wyoming (WY), Colorado (CO), New Mexico (NM) plus WA, ID, OR.

Commodity group and regional price indices were created as Törnqvist indices computed by the following formula:

$$(5)\ D_t = \exp\left[.5\sum_{i=1}^{K}(s_{it} + s_{i,t-1})\log(p_{it} / p_{i,t-1}) \right],$$

where $s_{it}=(p_{it}x_{it})/(p_t x_t)$, p_{it} and x_{it} are the price and quantity for individual commodity or state i in period t for i = 1,2,…,K, and K is the number of outputs, inputs, or states in the respective

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[4] For example, in Washington, outputs include: cattle, hogs, lamb, wool, honey, milk sold to plant and dealer, milk utilized on farm, broiler, chickens, eggs, corn, oats, barley, wheat, hay, fresh asparagus, processed asparagus, processed green beans, carrots, fresh sweet corn, processed sweet corn, processed cucumbers, dry beans, lettuce, peas, onions, potatoes, apples, apricots cherries, cranberries, grapes, peaches, plums, pears, strawberries, filberts, sugar beets, hops, mint, mushrooms, forestry, and nursery. California's larger number of outputs are mainly in vegetables, fruit and nuts categories.

[5] Except as noted, separate data series are included in each state for the following inputs: hired labor, self-employed labor, automobiles, trucks, tractors, other machinery, inventories, buildings, land, Bureau of Land Management public land (not in Washington), Forest Service public land, fuel (composite of four types), electricity, feed, seed, purchased livestock, fertilizer (hedonic index of N,P,K), pesticides (hedonic index of 34 herbicides, insecticides, and fungicides), equipment repairs, building repairs, custom services, contract labor, storage-transportation-marketing services, irrigation, insurance, miscellaneous inputs.

[6] For empirical studies conducted at a lower level of aggregation, it may be relevant to test for a larger number of hypothesized aggregate categories. Because of the frequency of ambiguous test results, we subsequently explore this issue for one state.

category. The year 1987 was used as the base year for computing group and regional price indices. The aggregate group or regional quantity indices were computed by dividing receipts (output revenue) or input expenditure by the corresponding group or regional price indices.

Empirical Results

Results of the stationarity and nonstationarity tests revealed that most nominal output and input group prices were nonstationary. The tests did not provide unambiguous support for stationarity of any series. All exceptions were indeterminate. The indeterminate groups included crops in AZ, capital in California, and labor in Washington, Idaho, New Mexico and Colorado. The general finding of nonstationarity in the nominal group prices was not surprising due to general price inflation over the data series.

While nominal price data were expected to be nonstationary, the deflated group prices were more likely to be stationary since their prices were divided by the aggregate output (input) price index. This was verified, particularly by the test results for outputs. Deflated output prices (livestock and crops) were stationary in nine of the 11 states. Deflated input prices (labor, capital, and materials), on the other hand, remained nonstationary or were indeterminate in all states. A summary of ADF and KPSS test results for each group of individual prices is reported in Table 1.

The Simes family-wise (multiple comparison) test results for consistent commodity-wise aggregation are presented in Table 2.[7] Test results are reported for each of the five aggregate commodity groups (livestock, crops, labor, capital, and materials) for each of the 11 states.

The GCCT is satisfied and consistent commodity-wise aggregation is supported when relative output (input) prices ρ_i are independent of every output (input) group price R_J. That is, for output prices, the test is that each individual relative output price is independent of both

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[7] Detailed results on all time series tests and individual independence tests are available upon request from the authors. They are included in the Reviewers' appendix, not intended for publication.

livestock and crop group prices. The number of tests listed in the table refers to the number of individual cointegration or correlation tests implemented for the group. These numbers were determined by the results of the stationarity and nonstationarity tests, and in turn determined the significance levels of the individual multiple comparison tests.

The specified joint significance level, α, was chosen to be 0.05 and 0.10 for the correlation and cointegration tests, respectively. As with the time series tests of nonstationarity, the 0.10 significance level was chosen to offset the low power of the test by increasing the likelihood of rejecting a true independence hypothesis. Following the Simes procedure, the null hypothesis of independence was rejected if $p(j) \leq j\alpha/n$, where $p(j)$ was the ordered p-value of each correlation or cointegration test, j was the order, and n was the total number of tests. If the smallest p-value was less than the respective significance level, then independence was rejected. If the smallest p-value was greater than the significance level, we continued to check the ordered p-values which were less than the chosen significant levels to determine whether any was less than its respective significance level. If so, the null hypothesis of independence was rejected. Tests for the GCCT were conducted using both nominal and deflated group prices (Lewbel, 1996). The last column of Table 1 reports the test conclusion of whether the GCCT was satisfied or not for the commodity grouping in each state. Both correlation and cointegration tests of independence were conducted for all five groups in nearly every state.

The correlation and cointegration tests generally gave different results and led to an ambiguous conclusion with regard to the GCCT. With both nominal and deflated data, it was most often, but not always, the correlation test results that implied rejection of the GCCT. In only four cases did the deflated data yield a different test result than did the nominal data when conducting the same test. In each of those cases, the deflated data supported the GCCT. In no case was the GCCT clearly rejected by all tests. In eight cases (labor in Oregon, Utah, and Wyoming, livestock and crops in California, crops in Oregon, and capital and materials in Utah), the GCCT was unambiguously supported by all tests. These results contrast to the conclusions of Davis, Lin and Shumway (2000). Using an admittedly less powerful and only partial testing procedure, they found unambiguous support for the GCCT for commodity-wise aggregation of U.S. and Mexican data in nearly 2/3 the output groups they tested, including livestock and crops.

The "ambiguous" result means that there is not enough evidence to accept the GCCT. Equivalently, there is not enough evidence to reject the GCCT with reasonable confidence. Consequently, GCCT tests for consistent geographic aggregation were conducted using data for each of these commodity groups. Following the same testing procedures as for commodity-wise aggregation, the GCCT test results for geographic aggregation in the Pacific Northwest are reported in Table 3. Unambiguous support for consistent aggregation across all three states was found for four of the five commodity groups – livestock, crops, labor, and materials. Only for capital was the evidence supporting consistent geographic aggregation of state-level data to this region ambiguous. Similar to the commodity-wise aggregation tests, the lack of full support for consistent geographic aggregation occurred with the correlation test. Our finding, however, gives greater support for consistent aggregation across states than that identified by Polson and Shumway (1990). They rejected consistent aggregation based on the identical technologies hypothesis for every pair of South Central states.

The GCCT test results for geographic aggregation across the 11 western states are reported in Table 4. Consistent geographic aggregation of state-level data to this larger Western region was supported for labor. Ambiguous test results were found for the other four groups – livestock, crops, capital and materials. As with the Pacific Northwest Region, the lack of full support for consistent aggregation occurred with the correlation test.

Since the tests for consistent geographic aggregation were sensitive to the size of the region, a related question is whether the tests for consistent commodity-wise aggregation are also sensitive to level of aggregation. To examine this issue, tests were conducted using Washington data for consistent commodity-wise aggregation within a partition of intermediate aggregates. The partition includes six output groups and seven input groups -- dairy, other livestock, grain, vegetables, fruit and nuts, other crops, hired labor, self-employed labor, land, other capital, energy, chemicals, and other purchased inputs.[8]

Test results for these categories are reported in Table 5. Among the 11 intermediate aggregate groups tested, unambiguous support for consistent aggregation was found only for dairy. Consistent aggregation was unambiguously rejected for grain. Test conclusions were ambiguous for the other nine groups. Consequently, the lower level of aggregation produced no clearer results regarding consistent aggregation than did the partition of two output and three input categories.

The ambiguous test conclusions were due mainly to different independence test conclusions when stationarity test results were indeterminate. One contributing factor to this indeterminacy may have been the length of the data series. With only 37 annual observations, ascertaining whether data are stationary or nonstationary is particularly difficult. Based on tests with longer series of similar data, it may be asserted that, in the indeterminate cases, the price series are more likely nonstationary than stationary. This assertion can be made more strongly for the nominal data, but is likely also true for the deflated data. If the data in each of the indeterminate cases

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[8] Tests were conducted for only five input categories since no aggregation of our data series was involved for the hired and self-employed labor categories.

were actually nonstationary, consistent aggregation would have received greater support for several categories. In no cases would it have received less support. Consistent commodity-wise aggregation would have been supported for all input categories in all states (with the exception of capital in California). Consistent geographic aggregation across all 11 Western states would have been supported for all input categories. Additional support for consistent aggregation in the output categories was minor – crops in Arizona and other crops in Washington.

Implications and Conclusions

Identifying and testing for sufficient conditions for consistent aggregation is an important issue in empirical production analysis. When sufficient conditions are satisfied, consistent multi-stage choice is possible. When consistent commodity-wise and geographic aggregation is achieved, estimates of aggregate models can provide reliable inferences about the underlying behavior of the disaggregate units, both those for commodities and those for individual geographic units. Erroneous parameter estimates and policy implications induced by aggregation error can be avoided.

This paper applied Lewbel's (1996) generalized composite commodity theorem (GCCT) and used the extended family-wise testing framework of Davis, Lin and Shumway (2000) and Davis (2002) to test for consistent aggregation across commodities and across states. This was the first application of GCCT tests for consistent geographic aggregation. Commodity-wise aggregation tests were conducted for input and output production aggregation hypotheses. Two aggregate output groups (livestock and crops) and three aggregate input groups (labor, capital and materials) were tested for consistency with the GCCT. Consistent geographic aggregation was tested for two groups of western states -- Pacific Northwest (Washington, Idaho, and Oregon) and West (11 states). Six intermediate output groups (dairy, other livestock, grain, vegetables, fruit and nuts, and other crops) and seven intermediate input groups (hired labor, self-employed labor, land, other capital, energy, chemicals, and other purchased inputs) in Washington were also examined for consistent commodity-wise aggregation.

Testing for consistency of the data with the GCCT involved a sequential testing procedure. Time series tests were first conducted for stationarity and, depending on the outcome of the time series tests, correlation or cointegration tests were conducted to determine whether various series were independent. The GCCT was satisfied when the distributions of all group price series and the ratios of individual prices within a group to their group price were independent. That required that the series were uncorrelated if stationary and non-cointegrated if nonstationary. Most (80 percent of) commodity-wise aggregation tests produced ambiguous results. Consistent geographic aggregation across the three Pacific Northwest states was supported for most aggregate commodities (livestock, crops, labor and materials) but was ambiguous across the 11 states in the Western region for all aggregates except labor (again 80 percent of the hypothesized groupings). Inferentially, additional unambiguous support for consistent aggregation would be provided if the data in the indeterminate cases of stationarity were in fact nonstationary, as is often observed with longer time series.

While the evidence provided in this paper in support of consistent aggregation at the state and regional level was not as strong as the evidence provided by Davis, Lin, and Shumway for commodity-wise aggregation in U.S. data, the support provided here was based on a more powerful testing procedure. In addition, although there was not overwhelming evidence in support of aggregation, there was clear evidence rejecting consistent aggregation for only one hypothesized intermediate aggregate grouping. Consequently, some limited support was found for modeling production at the regional and/or aggregate commodity level, which is often important for policy analysis. Given the preponderance of “ambiguous” consistency test results, though, the possibility of non-trivial aggregation error remains an important concern in models based on these groupings.

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Table 1. Summary of ADF and KPSS Test Results

State and Group	Number of Outputs or Inputs	Number of Stationary Series	Number of Non-Stationary Series	Number of Indeterminate Series
Arizona				
Livestock	8	3	2	3
Crops	26	10	10	6
Labor	2	0	0	2
Capital	9	0	6	3
Materials	15	1	6	8
California				
Livestock	11	6	2	3
Crops	64	29	25	10
Labor	2	0	1	1
Capital	9	5	1	3
Materials	15	1	9	5
Colorado				
Livestock	10	2	1	7
Crops	26	8	9	9
Labor	2	0	0	2
Capital	9	2	6	1
Materials	15	2	8	5
Idaho				
Livestock	8	1	2	5
Crops	22	12	6	4
Labor	2	0	1	1
Capital	9	1	1	7
Materials	15	1	8	6
Montana				
Livestock	9	4	0	5
Crops	11	5	3	3
Labor	2	0	0	2
Capital	9	1	7	1
Materials	15	1	9	5
Nevada				
Livestock	9	3	1	5
Crops	13	1	6	6
Labor	2	0	0	2
Capital	9	1	5	3
Materials	15	1	9	5
New Mexico				
Livestock	11	3	0	8
Crops	17	5	3	9
Labor	2	0	0	2
Capital	9	1	3	5
Materials	15	1	10	4

Table 1. Continued.

State and Group	Number of Outputs or Inputs	Number of Stationary Series	Number of Non-Stationary Series	Number of Indeterminate Series
Oregon				
Livestock	11	5	3	3
Crops	31	9	10	12
Labor	2	0	1	1
Capital	9	1	6	2
Materials	15	1	7	7
Utah				
Livestock	10	1	2	7
Crops	19	5	8	6
Labor	2	0	2	0
Capital	9	1	7	1
Materials	15	3	9	3
Washington				
Livestock	10	3	3	4
Crops	33	11	8	14
Labor	2	0	1	1
Capital	8	1	4	3
Materials	15	0	7	8
Wyoming				
Livestock	9	3	2	4
Crops	12	3	2	7
Labor	2	0	0	2
Capital	9	1	7	1
Materials	15	2	8	5
Total	665	161	257	247

Table 2. Simes Family-Wise Test Results for Consistent Commodity-Wise Aggregation

State and Group	Number of Outputs or Inputs	Hypothesis				GCCT Conclusion
		Nominal Prices		Deflated Prices		
		No Correlation	No Cointegration	No Correlation	No Cointegration	
Arizona						
Livestock	8	Reject (6)[a]	Not reject (10)	Reject (12)	(0)	Ambiguous
Crops	26	Reject (16)	Not reject (32)	Not reject (32)	(0)	Ambiguous
Labor	2	(0)	Not reject (6)	Reject (6)	Not reject (4)	Ambiguous
Capital	9	(0)	Not reject (27)	Reject (9)	Not reject (18)	Ambiguous
Materials	15	(0)	Not reject (42)	Reject (27)	Not reject (28)	Ambiguous
California						
Livestock	11	(0)	Not reject (10)	(0)	Not reject (10)	Yes
Crops	64	(0)	Not reject (70)	Not reject (2)	Not reject (70)	Yes
Labor	2	Reject (1)	Not reject (6)	Not reject (2)	Not reject (4)	Ambiguous
Capital	9	Reject (8)	Reject (8)	Reject (16)	Not reject (8)	Ambiguous
Materials	15	Reject (6)	Not reject (42)	Reject (12)	Not reject (28)	Ambiguous
Colorado						
Livestock	10	(0)	Not reject (16)	Reject (18)	(0)	Ambiguous
Crops	26	(0)	Not reject (34)	Reject (34)	(0)	Ambiguous
Labor	2	Reject (2)	Not reject (6)	Reject (2)	Not reject (6)	Ambiguous
Capital	9	Reject (3)	Not reject (21)	Reject (3)	Not reject (21)	Ambiguous
Materials	15	Reject (7)	Not reject (39)	Reject (7)	Not reject (39)	Ambiguous
Idaho						
Livestock	8	(0)	Not reject (14)	Reject (12)	(0)	Ambiguous
Crops	22	(0)	Not reject (20)	Reject (32)	(0)	Ambiguous
Labor	2	Reject (1)	Not reject (6)	Reject (1)	Not reject (4)	Ambiguous
Capital	9	Reject (8)	Not reject (24)	Reject (8)	Not reject (16)	Ambiguous
Materials	15	Reject (7)	Not reject (42)	Reject (7)	Not reject (28)	Ambiguous
Montana						
Livestock	9	(0)	Not reject (10)	Reject (18)	(0)	Ambiguous
Crops	11	(0)	Not reject (12)	Reject (16)	(0)	Ambiguous
Labor	2	(0)	Not reject (6)	Reject (4)	Not reject (6)	Ambiguous
Capital	9	(0)	Not reject (24)	Reject (4)	Not reject (24)	Ambiguous
Materials	15	(0)	Not reject (42)	Reject (12)	Not reject (42)	Ambiguous
Nevada						
Livestock	9	(0)	Not reject (12)	Reject (16)	(0)	Ambiguous
Crops	13	(0)	Not reject (24)	Reject (14)	(0)	Ambiguous
Labor	2	(0)	Not reject (6)	Reject (4)	Not reject (4)	Ambiguous
Capital	9	(0)	Not reject (24)	Reject (8)	Not reject (16)	Ambiguous
Materials	15	(0)	Not reject (42)	Reject (12)	Not reject (28)	Ambiguous

Table 2. Continued.

State and Group	Number of Outputs or Inputs	Hypothesis: Nominal Prices: No Correlation	Nominal Prices: No Cointegration	Deflated Prices: No Correlation	Deflated Prices: No Cointegration	GCCT Conclusion
New Mexico						
Livestock	11	(0)	Not reject (16)	Reject (22)	(0)	Ambiguous
Crops	17	(0)	Reject (24)	Not reject (28)	(0)	Ambiguous
Labor	2	Reject (2)	Not reject (6)	Reject (4)	Not reject (6)	Ambiguous
Capital	9	Reject (6)	Not reject (24)	Reject (12)	Not reject (24)	Ambiguous
Materials	15	Reject (5)	Not reject (42)	Reject (10)	Not reject (42)	Ambiguous
Oregon						
Livestock	11	(0)	Not reject (12)	Reject (16)	(0)	Ambiguous
Crops	31	(0)	Not reject (44)	Not Reject (42)	(0)	Yes
Labor	2	(0)	Not reject (6)	(0)	Not reject (4)	Yes
Capital	9	(0)	Not reject (24)	Reject (3)	Not reject (16)	Ambiguous
Materials	15	(0)	Not reject (42)	Reject (8)	Not reject (28)	Ambiguous
Utah						
Livestock	10	(0)	Not reject (18)	Reject (16)	(0)	Ambiguous
Crops	19	(0)	Not reject (28)	Reject (22)	Not reject (1)	Ambiguous
Labor	2	(0)	Not reject (6)	(0)	Not reject (6)	Yes
Capital	9	(0)	Not reject (24)	(0)	Not reject (24)	Yes
Materials	15	(0)	Not reject (36)	(0)	Not reject (36)	Yes
Washington						
Livestock	10	(0)	Not reject (14)	Reject (14)	(0)	Ambiguous
Crops	33	(0)	Not reject (44)	Reject (50)	(0)	Ambiguous
Labor	2	Reject (1)	Not reject (6)	Not reject (2)	Not reject (4)	Ambiguous
Capital	8	Reject (3)	Not reject (21)	Reject (8)	Not reject (14)	Ambiguous
Materials	15	Reject (8)	Not reject (45)	Reject (16)	Not reject (30)	Ambiguous
Wyoming						
Livestock	9	(0)	Not reject (12)	Reject (14)	(0)	Ambiguous
Crops	12	(0)	Not reject (18)	Reject (20)	(0)	Ambiguous
Labor	2	(0)	Not reject (6)	Not reject (2)	Not reject (6)	Yes
Capital	9	(0)	Not reject (24)	Reject (2)	Not reject (24)	Ambiguous
Materials	15	(0)	Not reject (39)	Reject (7)	Not reject (39)	Ambiguous

[a] The number of individual tests in the family-wise test is in parentheses.

Table 3. Simes Family-Wise Test Results for Consistent Geographic Aggregation, Pacific Northwest.

	Hypothesis				
	Nominal Prices		Deflated Prices		GCCT
Group and State	No Correlation	No Cointegration	No Correlation	No Cointegration	Conclusion
LIVESTOCK					
Washington		-2.833 (0.342)[a]	--	--	
Idaho		-3.272 (0.161)	--	--	
Oregon		-3.078 (0.231)	--	--	
Independence test		Not reject			Yes
CROPS					
Washington	--	--	0.233 (0.166)		
Idaho	--	--	-0.014 (0.932)		
Oregon	--	--	-0.309 (0.063)		
Independence test			Not reject		Yes
LABOR					
Washington	-0.041 (0.811)		--	--	
Idaho		-3.223 (0.177)		-3.549 (0.089)	
Oregon		-2.862 (0.328)		-2.649 (0.438)	
Independence test	Not reject	Not reject		Not reject	Yes
CAPITAL					
Washington		-2.535 (0.501)		-2.315 (0.621)	
Idaho	--	--	-0.437 (0.007)		
Oregon		-1.811 (0.842)		-1.680 (0.880)	
Independence test		Not reject	Reject	Not reject	Ambiguous
MATERIALS					
Washington	--	--	0.043 (0.820)		
Idaho		-1.654 (0.887)		-0.951 (0.980)	
Oregon		-2.957 (0.283)		-1.925 (0.801)	
Independence test		Not reject	Not reject	Not reject	Yes

[a] The first number is the test statistic for the cointegration or correlation test. P-value is in parentheses.

Table 4. Simes Family-Wise Test Results for Consistent Geographic Aggregation, 11 Western States.

	Hypothesis				
	Nominal Prices		Deflated Prices		GCCT
Group and State	No Correlation	No Cointegration	No Correlation	No Cointegration	Conclusion
LIVESTOCK					
Washington	--	--	-0.367 (0.025)		
Idaho		-2.294 (0.632)[a]	0.270 (0.106)		
Oregon	--	--	-0.033 (0.848)		
Nevada	--	--	0.479 (0.003)		
Montana	--	--	0.457 (0.005)		
Wyoming		-2.431 (0.558)	0.437 (0.007)		
New Mexico	--	-2.719 (0.401)	0.621 (0.0001)		
Utah		-3.903 (0.036)	-0.048 (0.778)		
Colorado		-1.845 (0.830)	0.240 (0.152)		
Arizona	--	--	0.410 (0.012)		
California		-2.484 (0.529)	-0.514 (0.001)		
Independence test		Not reject	Reject		Ambiguous
CROPS					
Washington	--	--	0.211 (0.211)		
Idaho	--	--	-0.026 (0.880)		
Oregon	--	--	0.097 (0.567)		
Nevada		-4.202 (0.015)	0.003 (0.986)		
Montana	--	--	-0.053 (0.756)		
Wyoming	--	--	0.080 (0.637)		
New Mexico	--	--	0.077 (0.650)		
Utah		-2.588 (0.472)	--	--	
Colorado		-4.157 (0.017)	0.174 (0.302)		
Arizona		-3.209 (0.182)	0.092 (0.589)		
California	--	--	-0.176 (0.298)		
Independence test		Reject	Not reject		Ambiguous
LABOR					
Washington		-2.329 (0.614)		-2.180 (0.690)	
Idaho		-2.476 (0.534)		-2.933 (0.294)	
Oregon		-2.658 (0.433)		-3.420 (0.119)	
Nevada		-2.644 (0.441)		-3.240 (0.171)	
Montana		-2.671 (0.426)		-2.302 (0.628)	
Wyoming		-2.855 (0.331)		-1.522 (0.916)	
New Mexico	--	--	--	--	
Utah		-2.945 (0.288)		-2.288 (0.635)	
Colorado		-3.008 (0.260)		-3.325 (0.145)	
Arizona	--	--	--	--	
California		-2.937 (0.292)		-2.756 (0.381)	
Independence test		Not reject		Not reject	Yes

Table 4. Continued.

	Hypothesis				
	Nominal Prices		Deflated Prices		GCCT
Group and State	No Correlation	No Cointegration	No Correlation	No Cointegration	Conclusion
CAPITAL					
Washington	--	--	-0.209 (0.215)		
Idaho		-2.679 (0.422)	-0.566 (0.0003)	-2.717 (0.402)	
Oregon		-2.237 (0.662)		-2.184 (0.688)	
Nevada		-3.032 (0.250)		-2.745 (0.387)	
Montana		-2.007 (0.769)		-1.780 (0.851)	
Wyoming		-1.496 (0.921)		-1.417 (0.935)	
New Mexico		-1.924 (0.802)		-2.873 (0.322)	
Utah		-1.718 (0.870)		-1.471 (0.926)	
Colorado		-3.041 (0.246)	0.201 (0.232)	-2.985 (0.270)	
Arizona		-3.558 (0.087)	0.342 (0.038)	-3.140 (0.207)	
California		-1.958 (0.789)	-0.152 (0.369)	-2.001 (0.771)	
Independence test		Not reject	Reject	Not reject	Ambiguous
MATERIALS					
Washington		-3.953 (0.031)	0.419 (0.010)	-2.755 (0.382)	
Idaho		-3.705 (0.061)		-2.435 (0.556)	
Oregon		-2.538 (0.499)		-2.589 (0.471)	
Nevada		-3.558 (0.087)		-1.798 (0.846)	
Montana		-2.947 (0.287)	-0.341 (0.039)	-2.889 (0.314)	
Wyoming		-4.219 (0.014)	-0.226 (0.179)	-3.294 (0.154)	
New Mexico		-2.948 (0.287)	0.018 (0.916)	-3.144 (0.206)	
Utah		-3.229 (0.175)	0.426 (0.009)	-2.119 (0.719)	
Colorado	--	--	-0.266 (0.111)		
Arizona		-2.283 (0.638)	0.498 (0.002)	-2.210 (0.675)	
California		-2.480 (0.531)	0.444 (0.006)	-1.497 (0.921)	
Independence test		Not reject	Reject	Not reject	Ambiguous

[a] The first number is the test statistic for the cointegration or correlation test. P-value is in parentheses.

Table 5. Simes Family-Wise Test Results for Consistent Commodity-Wise Aggregation of Intermediate groups in Washington

Group	Number of Outputs or Inputs	Hypothesis				GCCT Conclusion
		Nominal Prices		Deflated Prices		
		No Correlation	No Cointegration	No Correlation	No Cointegration	
Dairy	2	(0)[a]	Not reject (12)	(0)	Not reject (8)	Yes
Other Livestock	8	Reject (5)	Not reject (36)	Reject (20)	Reject (24)	Ambiguous
Grain	5	Reject (5)	Reject (24)	Reject (20)	Reject (16)	No
Vegetables	12	Reject (10)	Not reject (36)	Reject (40)	Reject (24)	Ambiguous
Fruit & nuts	10	Reject (6)	Reject (30)	Reject (28)	Not reject (24)	Ambiguous
Other crops	6	Reject (4)	Not reject (24)	Reject (16)	Not reject (16)	Ambiguous
Hired labor	1					No test
Self-employed labor	1					No test
Land	2	Reject (3)	Not reject (14)	Reject (4)	Not reject (12)	Ambiguous
Other capital	6	Not reject (9)	Not reject (18)	Reject (9)	Not reject (15)	Ambiguous
Energy	2	Reject (3)	Not reject (14)	Not reject (4)	Not reject (12)	Ambiguous
Chemicals	2	Reject (6)	Not reject (14)	Reject (8)	Not reject (12)	Ambiguous
Other inputs	11	Reject (12)	Not reject (77)	Reject (16)	Not reject (7)	Ambiguous

[a] The number of individual tests in the family-wise test is in parentheses.