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Testing aggregation consistency across geography and commodities*

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Consistent aggregation of production data across commodities and Western USA states was tested using Lewbel's generalised composite commodity theorem. The applicability of the generalised composite commodity theorem for testing consistent geographic aggregation was demonstrated and applied to two groups of states. Consistent commodity aggregation was tested in each state for two output groups and three input groups and in one state for a larger number of groups. Most tests for commodity aggregation supported consistent aggregation of inputs but not outputs. Consistent geographic aggregation was supported for each output and input category across Pacific Northwest states but only for inputs across all Western states.

1. Introduction

Issues related to aggregation consistency are often of great concern to researchers since aggregate data are widely used in economic analyses. Because economic analysis is frequently conducted and inferences are drawn using aggregate data and models, it is important to know whether behavioural 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 behaviour of disaggregate units (commodities, individuals, or firms). Others have constructed

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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 published literature is also concerned with the problems of choosing between aggregate and disaggregate models (Pesaran *et al.* 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). Further, in many cases, aggregate data are the only data available. 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 generalised 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,b).

The fourth sufficient condition, the generalised 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 fewer restrictions on technology or utility than the third condition. Although of very recent origin, the GCCT has been used to test for consistent aggregation of food consumption goods (Eales *et al.* 1998; Asche *et al.* 1999; Blundell and Robin 2000; Karagiannis and Mergos 2002) and agricultural production outputs (Davis *et al.* 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 published agricultural economics literature, Shumway and Davis (2001) identified 22 empirical studies that tested for consistent aggregation of food and/or agricultural commodities. Of the studies, 20 tested for consistent commodity-wise aggregation, 1 tested for consistent geographic aggregation (based on firm-wise aggregation conditions but using state-level data), and 1 tested for both. These studies collectively reported nearly 1500 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.

With the recent discovery that the GCCT provides an alternative sufficient condition for consistent commodity-wise aggregation, is it possible that it could be adapted to provide an alternative sufficient condition for firm-wise aggregation? One of the objectives of the present paper is to demonstrate that the GCCT is a valid sufficient condition for consistent aggregation across firms. The second objective is to apply the GCCT in tests both for consistent aggregation of outputs and inputs in each of the 11 Western USA states and for consistent geographic aggregation across three Pacific Northwest states and 11 Western states.

The applicability of the GCCT for consistent firm-wise aggregation is noted 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.

2. 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 *et al.* (2000) demonstrated that the GCCT could be used to test for consistent commodity-wise aggregation within a supply (production) context. The applicability of the GCCT for firm-wise aggregation 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.

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, they would satisfy the law of one price, and the Hicks composite commodity theorem would be satisfied. This result would give theoretical justification for consistent aggregation across firms. It is one of the important empirical questions addressed in the large published literature on spatial market integration. It is also often assumed to hold in trade models to enable aggregation over regions (Fackler and Goodwin 2001). However, even in competitive industries, heterogeneous prices actually exist across price-taking firms. Price heterogeneity may be a result of 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 logic is quite simple. Because consistent logarithmic aggregation through the GCCT requires only that: (i) netput supplies (positive if output, negative if input) be consistent with profit maximisation; and (ii) the distribution of the ratio of individual prices to their group price be independent from the distribution of group prices, then the proof follows immediately by generalising the concept of the individual. The individual can be anything: an output, an input, a firm, a consumer, a geographic unit, or anything else that defines a specific entity of interest. Alternatively, we can focus strictly on commodities and simply generalise the concept of a commodity. One might think of the same commodity attributed to different firms or locations as different commodities (à la Debreu 1959), and consider a grouping that goes across firms or locations.

Consider that the concept of an individual or commodity requires more than one dimension to fully describe. For example, consider the two dimensions of netput and firm. Let p_{ik} and x_{ik} be the price and quantity, respectively, of a netput produced or used by a firm. The subscripts i and k identify the specific firm and netput. When we consider the possibility of consistent aggregation, groupings go across one of the subscripts. In this example, if we group across netputs, we obtain commodity groupings such as those used by Lewbel (1996). If we group across firms or locations, we obtain geographic groupings. In the latter case, the proofs of Davis *et al.* (2000) apply with mere reinterpretation of the group indexing. When both of the sufficient conditions noted in the previous paragraph hold, Davis *et al.* (2000) proved that aggregate netput supply relationships retain the profit-maximising firm's properties of homogeneity, symmetry and nonnegativity.

To apply the GCCT in tests of consistent aggregation with commodities or individuals defined in multiple dimensions, it is critical to select the dimension (or entity) of interest that is to be indexed in the aggregation. For firm-wise aggregation, the entity is the firm. Therefore, the aggregate is a group of firms, and s_i is defined as the firm's share of all firms' revenue or expenditure for the given netput. To test for consistent aggregation over groups of firms, let s_{ik} be firm i's share of all firms' revenue or cost of netput k; that is, $p_{ik}x_{ik}/\Sigma_i p_{ik}x_{ik}$, where Σ_i sums over all firms. Taking the logarithm of the firm's price, $r_{ik} = \log(p_{ik})$, define $\boldsymbol{s_k}$ and $\boldsymbol{r_k}$ as netput k vectors of s_{ik} and r_{ik}, respectively, I identifies a subset (or group) of firms, P_{Ik} is netput k's group price index that depends on individual firm prices in the group I, and R_{Ik} is the logarithm of the group price index. Let $S_{Ik} = \Sigma_{i \in I} s_{ik}$ denote a group's revenue or cost share of netput k. Comparable to the notation for individual firms, $\boldsymbol{S_k}$ and $\boldsymbol{R_k}$ are netput k vectors of S_{Ik} and R_{Ik}. Also, $\rho_{ik} = \log(p_{ik}/P_{Ik})$ is the logarithm of the ratio of firm i's price to the group's price of netput k, and $\boldsymbol{\rho_k}$ is the k^{th} vector of the ratios.

Since the entities must be re-indexed based on which dimension is tested in the aggregation, we now drop the k subscript for notational simplicity.[1] In addition to netput supplies being consistent with profit-maximising behaviour, satisfaction of the GCCT requires that the distribution of the vector, $\boldsymbol{\rho}$, be independent of the distribution of the group logarithmic price vector $\boldsymbol{R}$. Following Lewbel's logic, let $\boldsymbol{R}^* = \boldsymbol{r} - \boldsymbol{\rho}$ and substitute this equation into $G_I^*(\boldsymbol{r})$. $F(\boldsymbol{\rho})$ is denoted as the distribution function of $\boldsymbol{\rho}$, and the following equation can be derived by integrating over this distribution:

[1] It is critical that i denotes the entity of interest to be indexed in the aggregation. For firm-wise aggregation, it is a firm so the aggregate is a group of firms, and s_i is the firm's share of all firms' revenue or expenditure for the given netput.

$$\int G_I^*(\boldsymbol{R}^* + \boldsymbol{\rho})\, dF(\boldsymbol{\rho}) = E[G_I^*(\boldsymbol{R}^* + \boldsymbol{\rho}) \mid \boldsymbol{R}] = G_I(\boldsymbol{R}). \tag{1}$$

This equation means that the group netput share equation, $G_I(\boldsymbol{R})$, is equal to the conditional expectation of the sum over individual netput share equations, $G_I^*(\boldsymbol{r})$ (Davis *et al.* 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 dimension.[2]

Consequently, the theoretical properties of individual netput supply functions (homogeneity, symmetry and positive semidefiniteness) are retained in group netput supply functions, $G_I(\boldsymbol{R})$, when the two conditions hold. Lim and Shumway (1992b) conducted nonparametric tests of the joint hypothesis of profit maximisation, convex technology, and nonregressive technical change for agricultural production in each of the contiguous 48 states in the USA. They failed to reject the joint hypothesis in any state. Therefore, given that the hypothesis of profit maximisation was not rejected for any geographic unit considered in the present 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.

3. Test procedures

The null hypothesis for the GCCT is that the distribution of the random vector $\boldsymbol{\rho}$ is independent of the vector $\boldsymbol{R}$. The test requires independence of $\boldsymbol{\rho}$ from $\boldsymbol{R}$. With $\boldsymbol{R}$ measured both in nominal and real terms (Lewbel 1996), the testing procedure entailed three steps.

We first examined the time series properties of each ρ_i and R_I, with R_I in both nominal and deflated form. Deflated group price, R_I, was calculated by dividing the output (input) group price by the price index for all outputs (inputs). The augmented Dickey-Fuller (ADF) test was used to test for a unit root (i.e., nonstationarity). Because of the low power of unit root tests, they were conducted with an alpha level of 0.10 using critical values calculated by Dickey and Fuller (1979). An examination of the time series plots of each series revealed no evidence of a time trend in the first differences, so the nonstationarity test equations did not include a trend term.

Second, based on the outcome of the time series test for each series, correlation and/or cointegration tests were applied to test for linear

[2] While the above demonstration of the applicability of the GCCT for consistent firm-wise aggregation could be generalised to other forms of aggregation, our documentation is only for aggregation of logarithms of prices (i.e., a geometric mean) and their corresponding quantity indexes. This is a nonlinear aggregation rather than the common linear aggregation across firms in which quantities are summed and the aggregate price is a weighted average of individual firm prices.

independence between each ρ_i, $i \in I$, and each series in $\boldsymbol{R}$.[3] If both ρ_i and R_J were found to be stationary, we used Spearman's rank correlation test to test the GCCT. If both ρ_i and R_J were nonstationary, we used Johanson's bivariate cointegration test. Since two series cannot be cointegrated if one is stationary and the other is nonstationary, linear independence was verified without applying any additional tests in that case (Granger and Hallman 1989).

Third, Simes (1986) multiple-comparison (family-wise) test procedure was used to draw independence conclusions. The Simes test is the most powerful of the multiple comparison test procedures (Davis 2003). It can be summarised 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 $\boldsymbol{R}$, the null hypothesis is rejected if any p-value is less than the respective significance level. Using $\alpha = 0.10$, we computed the p-value of each cointegration test following MacKinnon's (1994) approximate asymptotic distribution functions for unit root tests.[4]

Consistent commodity-wise aggregation in each state was tested first. Consistent state-wise aggregation was then tested using the commodity aggregates.

4. Data and aggregate groupings

Annual data for the period, 1960–1996, in 11 states of the Western USA were used in the present study. The data source was Ball's (unpubl. data, 2002) state-level agricultural output and input series for the contiguous 48 states in the USA. 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.[5] Although the number of outputs varies considerably among states, virtually every Western state produces one or more commodity

[3] These procedures only test for linear independence. It is still possible that some nonlinear dependency exists even though linear independence is not rejected.

[4] 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.

[5] 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.

within the broad categories of livestock, milk, poultry, feed grains, food grains, oilseeds, vegetables, fruits and nut crops.[6] Detailed input data cover the broad categories of labour, capital, land, chemicals, energy and materials.[7]

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 the present study, consistent aggregation tests were conducted in all states for outputs grouped into two hypothesised aggregate categories (livestock and crops) and inputs grouped into three hypothesised aggregate input categories (labour, capital, and materials).[8] To test state-wise aggregation consistency, two western regions were hypothesised: (i) Pacific Northwest, including Washington (WA), Idaho (ID), and Oregon (OR); and (ii) Western states, including California (CA), Arizona (AZ), Nevada (NV), Utah (UT), Montana (MT), Wyoming (WY), Colorado (CO), New Mexico (NM) plus WA, ID and OR.

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

$$D_t = \exp\left[0.5\sum_{i=1}^{K}(s_{it} + s_{i,t-1})\log(p_{it}/p_{i,t-1})\right], \tag{2}$$

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, p_t and x_t are price and quantity for the group of K commodities or states, $i = 1, 2, \ldots, K$, and K is the number of outputs, inputs, or states in the respective category. The year 1987 was used

[6] For example, in Washington, outputs include: cattle, hogs, lamb, wool, honey, milk sold to plant and dealer, milk utilised 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, and fruit and nuts categories.

[7] Except as noted, separate data series are included in each state for the following inputs: hired labour, self-employed labour, 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, fertiliser (hedonic index of N, P, K), pesticides (hedonic index of 34 herbicides, insecticides and fungicides), equipment repairs, building repairs, custom services, contract labour, storage-transportation-marketing services, irrigation, insurance and miscellaneous inputs.

[8] 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.

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.

5. Empirical results

Results of the ADF tests revealed that nonstationarity could not be rejected in any nominal output or input group prices or in most of the deflated input group prices. The only exceptions were deflated labour prices in Arizona, capital prices in Arizona and Montana, and materials prices in Idaho, Nevada, Oregon, and Washington. Except for California, nonstationarity was rejected in all deflated output group prices. The finding of nonstationarity in the nominal group prices was, not surprising, as a result of general price inflation over the data series. The general finding of stationary deflated group prices was also expected since their prices were divided by the aggregate output (input) price index. What was surprising was to find that most deflated input group price series remained nonstationary. A summary of nonstationarity test results for group and 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.[9] Test results are reported for each of the five aggregate commodity groups (livestock, crops, labour, capital and materials) in each of the 11 states.

The GCCT was satisfied and consistent commodity-wise aggregation was supported when relative output (input) prices, ρ_i, were independent of every output (input) group price, R_J. That is, for output prices, the test was that each individual relative output price was independent of both livestock and crop group prices. The number of tests listed in the table refers to the number of individual cointegration or correlation tests conducted for the group. These numbers were determined by the results of the 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 any $p(j) \leq j\alpha/n$, where $p(j)$ was the ordered

[9] Detailed results of all time series tests and individual independence tests are available upon request from the authors.

Table 1 Summary of nonstationarity test results

Geographical unit and group	Number of outputs or inputs†	Number of stationary series	Number of non-stationary series
Arizona			
Livestock	10	4	6
Crops	28	11	17
Labour	4	1	3
Capital	11	0	11
Materials	17	1	16
California			
Livestock	13	6	7
Crops	66	30	36
Labour	4	0	4
Capital	11	7	4
Materials	17	1	16
Colorado			
Livestock	12	3	9
Crops	28	10	18
Labour	4	0	4
Capital	11	2	9
Materials	17	2	15
Idaho			
Livestock	10	2	8
Crops	24	14	10
Labour	11	0	4
Capital	17	6	5
Materials	11	2	16
Montana			
Livestock	11	5	6
Crops	13	6	7
Labour	4	0	4
Capital	11	2	9
Materials	17	1	16
Nevada			
Livestock	11	4	7
Crops	15	2	13
Labour	4	0	4
Capital	11	3	8
Materials	17	2	15
New Mexico			
Livestock	13	4	9
Crops	19	6	13
Labour	4	0	4
Capital	11	1	10
Materials	17	1	16
Oregon			
Livestock	13	6	7
Crops	33	12	21
Labour	4	0	4
Capital	11	2	9
Materials	17	2	15

Table 1 Continued

Geographical unit and group	Number of outputs or inputs[†]	Number of stationary series	Number of non-stationary series
Utah			
Livestock	12	2	10
Crops	21	6	15
Labour	4	0	4
Capital	11	1	10
Materials	17	3	14
Washington			
Livestock	12	3	9
Crops	35	15	20
Labour	4	0	4
Capital	10	3	7
Materials	17	1	16
Wyoming			
Livestock	11	4	7
Crops	14	4	10
Labour	4	0	4
Capital	11	1	10
Materials	17	2	15
Livestock			
PNW[‡]	5	1	4
West	13	7	6
Crops4			
PNW	5	4	41
West	13	9	4
Labour			
PNW	5	1	4
West	13	2	11
Capital			
PNW	5	1	4
West	3	1	12
Materials			
PNW	5	1	4
West	13	1	12
Total	775	206	569

[†] Includes the group nominal and deflated prices. PNW, Pacific Northwest; West, 11 western states.

p-value of each correlation or cointegration test, j was the order, and n was the total number of tests for the group. 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 significance levels to determine whether any was less than its respective significance level. If so, the null hypothesis of linear independence was rejected. Tests for the GCCT were conducted using both nominal and deflated group prices (Lewbel 1996). The last column of table 2 reports the test conclusion

Table 2 Simes family-wise test results for consistent commodity-wise aggregation

State and group	Number of outputs or inputs	Hypothesis: Nominal prices: No correlation	Hypothesis: Nominal prices: No cointegration	Hypothesis: Deflated prices: No correlation	Hypothesis: Deflated prices: No cointegration	GCCT conclusion
Arizona						
Livestock	8	(0)†	Not reject (10)	Reject (6)	(0)	Reject
Crops	26	(0)	Not reject (32)	Reject (20)	(0)	Not reject
Labour	2	(0)	Not reject (6)	(0)	Not reject (4)	Not reject
Capital	9	(0)	Not reject (27)	(0)	Not reject (18)	Not reject
Materials	15	(0)	Not reject (42)	Not reject (1)	Not reject (28)	Not reject
California						
Livestock	11	(0)	Not reject (10)	(0)	Not reject (10)	Not reject
Crops	64	(0)	Not reject (68)	(0)	Not reject (68)	Not reject
Labour	2	(0)	Not reject (6)	(0)	Not reject (4)	Not reject
Capital	9	(0)	Not reject (9)	Reject (6)	Not reject (8)	Reject
Materials	15	(0)	Not reject (42)	Not reject (2)	Not reject (28)	Not reject
Colorado						
Livestock	10	(0)	Not reject (16)	Reject (4)	(0)	Reject
Crops	26	(0)	Not reject (32)	Reject (20)	(0)	Reject
Labour	2	(0)	Not reject (6)	(0)	Not reject (6)	Not reject
Capital	9	(0)	Not reject (21)	(0)	Not reject (21)	Not reject
Materials	15	(0)	Not reject (39)	(0)	Not reject (39)	Not reject
Idaho						
Livestock	8	(0)	Not reject (14)	Not reject (22)	(0)	Not reject
Crops	22	(0)	Not reject (18)	Reject (26)	(0)	Reject
Labour	2	(0)	Not reject (6)	(0)	Not reject (4)	Not reject
Capital	9	(0)	Not reject (9)	Reject (6)	Not reject (6)	Ambiguous
Materials	15	(0)	Not reject (42)	Reject (1)	Not reject (28)	Ambiguous

Table 2 Continued

State and group	Number of outputs or inputs	Hypothesis				GCCT conclusion
		Nominal prices		Deflated prices		
		No correlation	No cointegration	No correlation	No cointegration	
Montana						
Livestock	9	(0)	Not reject (10)	Reject (8)	(0)	Reject
Crops	11	(0)	Not reject (12)	Reject (10)	(0)	Reject
Labour	2	(0)	Not reject (6)	(0)	Not reject (4)	Not reject
Capital	9	(0)	Not reject (24)	Not reject (1)	Not reject (16)	Not reject
Materials	15	(0)	Not reject (42)	Not reject (1)	Not reject (28)	Not reject
Oregon						
Livestock	11	(0)	Not reject (12)	Reject (10)	(0)	Reject
Crops	31	(0)	Not reject (40)	Reject (22)	(0)	Reject
Labour	2	(0)	Not reject (6)	(0)	Not reject (4)	Not reject
Capital	9	(0)	Not reject (21)	Reject (1)	Not reject (14)	Ambiguous
Materials	15	(0)	Not reject (42)	Reject (1)	Not reject (28)	Ambiguous
Nevada						
Livestock	9	(0)	Not reject (12)	Reject (6)	(0)	Reject
Crops	13	(0)	Not reject (24)	Reject (2)	(0)	Reject
Labour	2	(0)	Not reject (6)	(0)	Not reject (4)	Not reject
Capital	9	(0)	Not reject (18)	Reject (3)	Not reject (12)	Ambiguous
Materials	15	(0)	Not reject (42)	Reject (1)	Not reject (28)	Not reject
New Mexico						
Livestock	11	(0)	Not reject (16)	Reject (6)	(0)	Reject
Crops	17	(0)	Not reject (24)	Not reject (10)	(0)	Reject
Labour	2	(0)	Not reject (6)	(0)	Not reject (6)	Not reject
Capital	9	(0)	Not reject (24)	(0)	Not reject (24)	Not reject
Materials	15	(0)	Not reject (36)	(0)	Not reject (36)	Not reject

Table 2 Continued

State and group	Number of outputs or inputs	Hypothesis: Nominal prices: No correlation	Hypothesis: Nominal prices: No cointegration	Hypothesis: Deflated prices: No correlation	Hypothesis: Deflated prices: No cointegration	GCCT conclusion
Utah						
Livestock	10	(0)	Not reject (18)	Reject (2)	(0)	Reject
Crops	19	(0)	Not reject (28)	Reject (10)	(0)	Reject
Labour	2	(0)	Not reject (6)	(0)	Not reject (6)	Not reject
Capital	9	(0)	Not reject (24)	(0)	Not reject (24)	Not reject
Materials	15	(0)	Not reject (36)	(0)	Not reject (36)	Not reject
Washington						
Livestock	10	(0)	Not reject (16)	Reject (4)	(0)	Reject
Crops	33	(0)	Not reject (38)	Reject (28)	(0)	Reject
Labour	2	(0)	Not reject (6)	(0)	Not reject (4)	Not reject
Capital	8	(0)	Not reject (15)	Reject (3)	Not reject (10)	Ambiguous
Materials	15	(0)	Not reject (45)	(0)	Not reject (30)	Not reject
Wyoming						
Livestock	9	(0)	Not reject (12)	Reject (6)	(0)	Reject
Crops	12	(0)	Not reject (6)	Reject (6)	(0)	Reject
Labour	2	(0)	Not reject (6)	(0)	Not reject (6)	Not reject
Capital	9	(0)	Not reject (24)	(0)	Not reject (24)	Not reject
Materials	15	(0)	Not reject (39)	(0)	Not reject (39)	Not reject

† The number of individual tests in the family-wise test is in parentheses.

of whether or not the GCCT was rejected for a commodity grouping in the respective state. Both correlation and cointegration tests of independence were required in every state.

For the hypothesis of consistent aggregation to be supported, the GCCT could not be rejected in either nominal or deflated data. However, because of the limited number of annual observations (37) and the low power of the nonstationarity test, ascertaining whether data were stationary or nonstationary was particularly difficult. It is possible that a series recorded as stationary was actually nonstationary, and vice versa. Consequently, when both correlation and cointegration tests were conducted for any group with the same type of data (nominal or deflated) and gave conflicting test results, the GCCT test conclusion was recorded as ambiguous.

The GCCT was rejected for livestock in all states except California and Idaho. For crops, it was rejected in all states except Arizona and California. Among input categories, the GCCT was unambiguously rejected only for capital in California. The test conclusion was ambiguous for capital in four additional states (Idaho, Oregon, Nevada and Washington) and for materials in two states (Idaho and Oregon). In each case of ambiguity, it was the correlation test result that implied rejection of the GCCT and the cointegration test result that supported it. These results contrast to the conclusions of Davis *et al.* (2000). Using an admittedly less powerful and only partial testing procedure, they found unambiguous support for the GCCT for commodity-wise aggregation in more than half the Mexican output groups they tested and three-quarters of the USA output groups, including livestock and crops.

Using commodity aggregates and 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 each of the five commodity aggregates. Our finding 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. The test conclusions were similar to those for consistent commodity-wise aggregation. Consistent geographic aggregation of state-level data to this larger Western region was supported for each input group and rejected for each output group.

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

Table 3 Simes family-wise test results for consistent geographic aggregation, Pacific Northwest

Group and state	Hypothesis				GCCT conclusion
	Nominal prices		Deflated prices		
	No correlation	No cointegration	No correlation	No cointegration	
Livestock					
Washington		–2.833 (0.342)[†]	–	–	
Idaho		–3.272 (0.161)	–	–	
Oregon		–3.078 (0.231)	–	–	
Independence test		Not reject	–	–	Not reject
Crops					
Washington	–	–	0.233 (0.166)		
Idaho	–	–	–0.014 (0.932)		
Oregon	–	–	–0.309 (0.063)		
Independence test			Not reject		Not reject
Labour					
Washington	–	–	–	–	
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
Capital					
Washington		–2.535 (0.501)		–2.315 (0.621)	
Idaho	–	–	–	–	
Oregon		–1.811 (0.842)		–1.680 (0.880)	
Independence test		Not reject		Not reject	Not reject
Materials					
Washington	–	–	–	–	
Idaho		–1.654 (0.884)		–0.954 (0.980)	
Oregon		–2.957 (0.283)		–1.925 (0.801)	
Independence test		Not reject		Not reject	Not reject

[†] The first number is the test statistic for the cointegration or correlation test. P-value is in parentheses. –, no test conducted; this is because the nonstationarity tests revealed one series stationary and the other nonstationary, so the series can not be cointegrated.

Table 4 Simes family-wise test results for consistent geographic aggregation, 11 Western States

	Hypothesis				
	Nominal prices		Deflated prices		
Group and state	No correlation	No cointegration	No correlation	No cointegration	GCCT conclusion
Livestock					
Washington	–	–	0.367 (0.025)		
Idaho	–	–	0.270 (0.106)		
Oregon	–	–	–0.033 (0.848)		
Nevada	–	–	0.479 (0.003)		
Montana	–	–	0.457 (0.005)		
Wyoming		–2.431 (0.558)[†]	–	–	
New Mexico		–2.719 (0.401)	–	–	
Utah		–3.903 (0.036)	–	–	
Colorado		–1.845 (0.830)	–	–	
Arizona	–	–	0.410 (0.012)		
California		–2.484 (0.529)	–	–	
Independence test		Not reject	Reject		Reject
Crops					
Washington	–	–	0.211 (0.211)		
Idaho	–	–	–0.026 (0.880)		
Oregon	–	–	0.097 (0.567)		
Nevada		–4.202 (0.015)	–	–	
Montana	–	–	–0.053 (0.756)		
Wyoming	–	–	0.080 (0.637)		
New Mexico	–	–	0.077 (0.650)		
Utah		–2.588 (0.472)	–	–	
Colorado		–14.157 (0.017)	–	–	
Arizona	–	–	0.092 (0.589)		
California	–	–	–0.176 (0.298)		
Independence test		Reject	Not reject		Reject

Table 4 Continued

Group and state	Hypothesis: Nominal prices: No correlation	Hypothesis: Nominal prices: No cointegration	Hypothesis: Deflated prices: No correlation	Hypothesis: Deflated prices: No cointegration	GCCT conclusion
Labour					
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	Not reject
Capital					
Washington	–	–	–	–	
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)		–2.985 (0.270)	
Arizona		–3.558 (0.087)		3.140 (0.207)	
California		–1.958 (0.789)		2.001 (0.771)	
Independence test		Not reject		Not reject	Not reject

Table 4 Continued

	Hypothesis				
	Nominal prices		Deflated prices		
Group and state	No correlation	No cointegration	No correlation	No cointegration	GCCT conclusion
Materials					
Washington		–3.953 (0.031)		–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)		–2.889 (0.314)	
Wyoming		–4.219 (0.014)		–3.294 (0.154)	
New Mexico		–2.948 (0.287)		–3.144 (0.206)	
Utah		–3.229 (0.175)		–2.119 (0.719)	
Colorado	–	–	–	–	
Arizona		–2.283 (0.638)		–2.210 (0.675)	
California		–2.480 (0.531)		–1.497 (0.921)	
Independence test		Not reject		Not reject	Not reject

† The first number is the test statistic for the cointegration or correlation test. P-value is in parentheses. –, no test conducted; this is because the nonstationarity tests revealed one series stationary and the other nonstationary, so the series can not be cointegrated.

consistent commodity-wise aggregation within a partition of intermediate aggregates. The partition included six output groups and seven input groups: dairy, other livestock, grain, vegetables, fruit and nuts, other crops, hired labour, self-employed labour, land, other capital, energy, chemicals, and other purchased inputs.

Test results for these categories are reported in table 5. Of the six intermediate aggregate output groups tested, support for consistent aggregation was found for dairy and other crops and rejected for the other four categories (other livestock, grain, vegetables, fruit and nuts). Of the seven input groups, tests were not required for two because no aggregation was involved. Test conclusions for consistent aggregation were ambiguous for other capital and not rejected for the remaining four categories. Consequently, the lower level of aggregation produced no clearer results regarding consistent aggregation than did the partition of two output and three input categories.

6. Implications and conclusions

Identifying and testing 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 behaviour of the disaggregate units, both those for commodities and those for individual geographic units, without the need to consider aggregation error in the estimation. Erroneous parameter estimates and policy implications induced by aggregation error can be avoided.

The present paper documented that, in addition to testing for consistent commodity-wise aggregation, Lewbel's (1996) GCCT can be used to test for consistent geographic aggregation. Empirical testing procedures were then implemented to test for consistency in aggregation, both across commodities and geography. Two aggregate output groups (livestock and crops) and three aggregate input groups (labour, capital and materials) were tested for consistency with the GCCT. Consistent geographic aggregation was tested for two groups of western states: the Pacific Northwest (Washington, Idaho and Oregon) and the West (11 states). Six intermediate output groups (dairy, other livestock, grain, vegetables, fruit and nuts, and other crops) and seven intermediate input groups (hired labour, self-employed labour, land, other capital, energy, chemicals, and other purchased inputs) in Washington were also examined for consistent commodity-wise aggregation.

Consistent commodity-wise aggregation was supported by the test results for most input categories in each state, but little support was provided for consistent aggregation of output categories. Consistent geographic aggregation

Table 5 Simes family-wise test results for consistent commodity-wise aggregation of intermediate groups

State and group	Number of outputs or inputs	Hypothesis				GCCT conclusion
		Nominal prices		Deflated prices		
		No correlation	No cointegration	No correlation	No cointegration	
Dairy	2	(0)[†]	Not reject (12)	(0)	Not reject (8)	Not reject
Other Livestock	8	(0)	Not reject (36)	Reject (4)	Reject (24)	Reject
Grain	5	(0)	Reject (24)	Reject (2)	Reject (16)	Reject
Vegetables	12	(0)	Not reject (42)	Reject (10)	Reject (28)	Reject
Fruit & nuts	10	(0)	Reject (36)	Reject (8)	Reject (24)	Reject
Other crops	6	(0)	Not reject (24)	Not reject (4)	Not reject (16)	Not reject
Hired labour	1	–	–	–	–	No test
Self-employed labour	1	–	–	–	–	No test
Land	2	(0)	Not reject (14)	(0)	Not reject (12)	Not reject
Other capital	6	(0)	Not reject (21)	Reject (3)	Not reject (18)	Ambiguous
Energy	2	(0)	Not reject (14)	(0)	Not reject (12)	Not reject
Chemicals	2	(0)	Not reject (14)	(0)	Not reject (12)	Not reject
Other inputs	11	(0)	Not reject (77)	(0)	Not reject (66)	Not reject

[†] The number of individual tests in the family-wise test is in parentheses. –, no test conducted because there was only one input in the group.

was supported for all output and input aggregates across the three Pacific Northwest states. Consistent geographic aggregation across the 11 states in the Western region was also generally supported for inputs, but only modest support was found for outputs.

The evidence provided in the present paper provides limited support for the hypothesis of consistent aggregation at the state and regional level. It also identifies remaining groupings for which sufficient technology conditions for consistent aggregation warrant testing in order to minimise the possibility of non-trivial aggregation error in models based on these groupings. If such tests are not conducted or if the consistent aggregation hypothesis is rejected by them, then aggregation (measurement) errors should be formally incorporated in economic models based on any of these aggregate partitions.

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