Market Integration, Efficiency of Arbitrage, and Imperfect Competition: Methodology and Application to U.S. Celery

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This paper develops and applies a methodology to test for efficiency in interregional commodity arbitrage. The methodology is empirically manifest as a switching regression model with three regimes: efficient arbitrage, relative shortage, and relative glut. Results from application of the model to U.S. celery marketing indicate significant departures from efficient arbitrage for both California and Florida celery.

Key words: Arbitrage, celery, imperfect competition, law of one price, market integration, price efficiency.

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Markets are fundamental to economics, and it is not surprising that economists have devoted considerable effort to their definition and measurement. Recent examples in agricultural economics include Houck, Ravillion, Goodwin and Schroeder, Carter and Hamilton, and Goodwin, Grennes, and Wohlgenant.

A methodology developed recently by Spiller and Huang (SH) to geographically define wholesale gasoline markets may contribute importantly to this inquiry. This paper extends the SH approach and adapts it to an agricultural markets context, with a specific application to U.S. Celery markets.

The concept of geographic markets is particularly relevant to agriculture because agricultural products are often bulky and/or perishable and, hence, costly to transport. Based on Marshall's classical definition, two regions are in the same economic market if their prices for a homogeneous good differ by the interregional transportation cost. In other words, regions are in the same economic market if they are linked by arbitrage. Alternative statements of the same concept are that the two regional markets are integrated (Goodwin and Schroeder) and that the "law of one price" holds between the two regions (Carter and Hamilton).

Information on the geographic extent (integration) of markets provides specific evidence as to the effectiveness of arbitrage (Carter and Hamilton) and the efficiency of pricing (Buccola). It also provides insight into the competitive nature of markets because the Marshallian market integration condition is indeed predicated upon competitive arbitrage between markets. Hence, failure of the law of one price to hold may signal actual departures from competition in some regions or else the potential for sellers in some regions to raise prices without stimulating offsetting competitive arbitrage.

The traditional methodology to study market integration relies upon correlations between the prices in pairs of regions (Richardson, Horowitz). For example, a typical regression model might be

(1) $P_t^1 = \beta_0 + \beta_1 P_t^2 + \beta_2 T_t + e_t$,

where P_t^i, i = 1, 2 is the price in region i at time t for a homogeneous good, T_t is the cost at t to transport a unit of the good between the two regions, and e_t is a random error term. A test of integration is provided by the joint hypothesis:

(2) Ho: $\beta_0 = 0$, $\beta_1 = \beta_2 = 1.0$.

Because common shifts in supply and demand may induce substantial correlation among the P_t^i even in the absence of interregional arbitrage, analysts have turned recently to variations of (1) based upon correlations of price differences (Stigler and Sherwin, Ravillion, Carter and Hamilton). Other recent approaches have focused on incorporating agents price expectations into the arbitrage model (Goodwin and Schroeder, Goodwin, Grennes, and Wohlgenant). Lingering problems in arbitrage models include the following:

1. The choice of one price as predetermined is often arbitrary and may induce simultaneity biases;

2. Transportation costs are usually unobservable and, hence, omitted from the analysis with the usual omitted variables consequences;

3. The approach is fundamentally inflexible in that integration is treated as an all or nothing proposition, whereas in reality regions often may be linked by arbitrage in some periods but not in others, with the probability of arbitrage at time t depending upon supply-demand conditions in each region at t as well as the magnitude of T_t.

We turn now to describe the basic SH model, a methodology which appears to transcend these shortcomings of the traditional approaches. Moreover, with the extension proposed here, the approach is capable of addressing a number of market integration questions relevant to agriculute. Our application to celery markets provides an illustration.

The Basic Model and an Extension

The SH model is applicable to seperate regions that have their own supplies and demands for the product in question. The product may be shipped at a cost across regions. This scenario is characteristic, for example, of many livestock products, including beef, pork, and poultry. Given that each region has its own supply and demand, it is possible to identify autarkic prices in each region.

SH express the reduced form equations of autarky prices as

(3) $P_t^{1A} = \pi^1 + \epsilon_t^1$,

(4) $P_t^{2A} = \pi^2 + \epsilon_t^2$,

where the π^i are constant means and the ϵ_t^i represent random shocks to the markets. Given free trade across regions, the actual prices, P_t^1, P_t^2, may differ from the autarky prices. Specifically, if $|P_t^{1A} - P_t^{2A}| < T_t$, no profitable arbitrage opportunities exist and

$$P_t^1 = P_t^{1A},\ P_t^2 = P_t^{2A}.$$

However, if the autarky price difference exceeds T_t, SH assume that competitive interregional shipments will take place until the observed prices in each region differ by exactly T_t. In this case the markets are integrated, and

$$P_t^2 - P_t^1 = T_t' > 0,$$

where for simplicity region 2 is assumed to be the higher price region.

Let T_t be modelled as a random variable with constant mean, T:

(5) $T_t = T + v_t$, where $v_t \sim N(0, \sigma_v^2)$.

The probability at time t of no arbitrage opportunities between the two regions (i.e., the probability of the markets being <u>unintegrated</u>) is the constant, λ, where

$\lambda = \text{Prob}\{ P_t^{2A} - P_t^{1A} < T + v_t \}$,

$= \text{Prob}\{ \pi^2 - \pi^1 + (\epsilon_t^2 - \epsilon_t^1) - v_t < T \}$.

It follows that λ is a function of π^1, π^2, T, σ_v^2, and the distribution parameters of the ϵ_t^i. The probability of observing binding arbitrage (market integration) at time t is merely 1 - λ, where $\lambda \approx 0$ signifies regions that are almost always integrated (in the same Marshallian economic market) and so forth.

The above model may be expressed as a switching regression system and estimated using maximum likelihood methods. Notice that the SH approach surmounts the difficulties noted earlier in implementing the traditional approach: (1) prices are not treated as predetermined variables, (2) transportation costs are endogenous and estimated in the model, and (3) the probability that markets are integrated is allowed to vary continuously.

Our purpose now is to extend the basic SH framework to analyze prototypical agricultural market settings. Many agricultural products are produced in only one or a few concentrated regions and, hence, do not conform directly to the SH paradigm, wherein regions have indiginous supply sources. For example, U.S. supplies of many fruits and vegetables, depending upon the season, emanate mainly from California and/or Florida. In these cases shipments typically flow from the producing region to various terminal markets across the country, and regional autarkic markets do not make sense.

The parallel question that arises in these settings is whether product allocation from the producing region to consuming regions takes place efficiently or whether periodic surpluses or gluts occur as the result of product misallocations (Buccola 1983, 1985, Berger et al.). Episodes of arbitrage failure cannot be attributed to autarkic market equilibria in these cases. Rather, they must be explained by inefficiencies in arbitrage or, possibly, imperfect competition. Therefore, whereas the prototype SH methodology treats efficiency of arbitrage as a maintained hypothesis, and tests for autarky or integration, equally relevant to agriculture are models wherein markets must logically be linked by arbitrage and tests for the efficiency and/or competitiveness of the arbitrage process are at issue.

For parsimony of presentation, we develop this extension of the SH methodology in the context of our application to celery, recognizing, however, the approach's applicability to similar product settings. During the summer and fall months, California supplies the dominant portion (about 80 - 85 percent) of U.S. celery. Shipments data confirm that California provides the major summer supply source for celery in all key U.S. terminal markets.

The winter and spring celery market (roughly mid Dec. to mid June) is different, however, because Florida enters as a major producer, accounting for about 25 percent of domestic supplies. During these months Florida ships celery to all major terminal markets except those on the West Coast.

Focusing attention first on celery product flows during the summer months, we assume that California celery is allocated competitively. This assumption is very plausible in that a large number of growers produce celery, and there is no centralized mechanism to coordinate shipments (Berger et al.). Suppose initially that product flows are also efficient. Then denoting California (C) FOB prices with a lower case p and wholesale terminal market prices with the corresponding upper case P^i, i=1,...,n, we have the following equilibrium arbitrage condition:

$$(6)\ p_{C,t} = P_t^1 - T_t^1 = P_t^2 - T_t^2 = \cdots = P_t^n - T_t^n.$$

Departures from (6) should trigger product reallocations from low- to high-price terminals to restore the equality.

However, if product is not allocated efficiently due to risk factors, imperfect information, significant shipment lags, etc. (see generally Buccola 1983), then periodic gluts or shortages may appear in the various terminals and (6) will not hold for all t. For example, Berger et al. speculate that California causes periodic gluts in Eastern markets during summer months by making large shipments with "no pre-arranged destination or price (p. 35)."

To extend the SH methodology to test for inefficient product allocation, define three regimes that exhaust the possible arbitrage conditions between the producing region and any terminal market i:

$$(7a)\ P_t^i - p_{C,t} = T + v_t \text{ with prob } 1-\lambda_1-\lambda_2$$

(7b) $P_t^i - p_{c,t} = T + v_t + u$ with prob λ_1

(7c) $P_t^i - p_{c,t} = T + v_t - u$ with prob λ_2

Here u is defined as a positive random variable so that (7b) defines a regime wherein the wholesale terminal price exceeds the FOB price plus transactions costs--a relative shortage situation. Alternatively (7c) corresponds to a market glut, a situation where the terminal price is depressed below the FOB price plus shipment costs.

The equations in (7), thus, define a switching regression model with three regimes: efficient arbitrage, shortage, and glut. To estimate the model, the likelihood function may be formulated as follows:

(8) $L = \Pi_{t=1}^{n} [\lambda_1 f_t^1 + \lambda_2 f_t^2 + (1-\lambda_1-\lambda_2) f_t^3]$

where f_t^1, f_t^2, and f_t^3 are, respectively, the density functions of (7a), (7b), and (7c), and n is the number of observations. To specify these densities we assume that u_t is distributed independently of v_t with a half normal distribution, i.e., a $N(0,\sigma_u^2)$ distribution truncated from below at zero. Then following the notation of SH, we define $Y_t = P_t^i - p_{c,t}$ and express the densities as follows:

$$f_t^1 = \left[\frac{2}{(\sigma_u^2+\sigma_v^2)^{.5}}\right] \left[\phi\left[\frac{Y_t - T}{(\sigma_u^2+\sigma_v^2)^{.5}}\right]\right] \left[1 - \Phi\left[\frac{-(Y_t - T)\sigma_u/\sigma_v}{(\sigma_u^2+\sigma_v^2)^{.5}}\right]\right]$$

$$f_t^2 = \left[\frac{2}{(\sigma_u^2+\sigma_v^2)^{.5}}\right] \left[\phi\left[\frac{Y_t - T}{(\sigma_u^2+\sigma_v^2)^{.5}}\right]\right] \left[1 - \Phi\left[\frac{(Y_t - T)\sigma_u/\sigma_v}{(\sigma_u^2+\sigma_v^2)^{.5}}\right]\right]$$

$$f_t^3 = \frac{1}{\sigma_v} \phi\left[\frac{Y_t - T}{\sigma_v}\right],$$

where $\phi(\,)$ denotes the standard normal density function, and $\Phi(\,)$ denotes the corresponding cumulative distribution function for the standard normal. The parameters T, λ_1, λ_2, σ_v^2, and σ_u^2 can be estimated by maximizing the log of (8).

During Florida's winter production cycle the Florida analogue to the California efficient arbitrage condition,(6), can be formulated and also tested via (8). Some complications arise, however, due to the unique features of Florida celery marketing. Florida celery is marketed under the auspices of the Florida Celery Exchange to which nearly all Florida celery growers belong (Berger et al.). Florida celery marketing is also regulated by a federal marketing order featuring flow-to-market provisions. The Exchange determines prices on Mondays and Wednesdays which are then passed on to the shipping agents.

Contracts with growers give the Exchange title to the celery and complete control over its marketing (Kilmer).

Thus, marketing of celery is much more coordinated in Florida than California. A key question is whether Florida shippers employ this coordination to price discriminate across consuming markets in prototypical marketing order fashion (e.g., Ippolito and Masson, Shepard). Alternatively, pervasive competition from California may effectively mitigate these opportunities. This question has been analyzed recently by Taylor and Kilmer who concluded that "the weight of empirical evidence. . . suggests that the Florida celery industry has not enhanced price above [the competitive level] (p.41)."

To explore this question a bit further using the modified SH framework, note that profit maximizing price discrimination requires equating of net marginal revenues across markets. Thus, a price discrimination equilibrium for Florida would be

(9) $MR^1_{F,t} - T^1_{F,t} = MR^2_{F,t} - T^2_{F,t} = \cdots = MR^n_{F,t} - T^n_{F,t} \leq p_{F,t}$,

where the $MR^i_{F,t}$ denote marginal revenue from Florida celery sales to the various terminal markets i at time t, and $T^i_{F,t}$ are the corresponding per unit transportation costs. The Florida grower price, $p_{F,t}$, would represent a blend price based on revenues from the various terminal markets.

If Florida has no market power, demand for its celery is perfectly elastic, $MR^i_{F,t} = P^i_{F,t}$, for all i, and (9) collapses to the competitive equilibrium condition, (6). Celery has few substitutes, so aggregate celery demand is quite inelastic (Shonkwiler and Pagoulatos, Taylor and Kilmer). The residual demand facing Florida producers at any price is essentially this aggregate demand less the competing California supply at that price. Therefore, Florida's greatest opportunities to exercise market power through its Exchange and marketing order are in Southern markets where it has a decided transportation cost advantage. Studies which test market power using aggregate data, such as Taylor and Kilmer, may not capture these pockets of localized market power.

In regions where Florida has market power, the terminal market price, $P^i_{F,t}$, exceeds the grower price, $p_{F,t}$, plus transport cost, $T^i_{F,t}$, by an additional markup, say M^i_t:

$$P^i_{F,t} = p_{F,t} + T^i_{F,t} + M^i_t.$$

The modified SH model summarized in (6), (7), and (8) cannot formally distinguish the two components of the $P^i_{F,t}$, - $p_{F,t}$ price difference. That is, the coefficient, $\hat{T}_F$ from maximizing the log of (8) will include both T^i_F (see eq. (5)) and a sample average for M^i_t. Nonetheless, because inferences about the relative rankings of the T_F^i can be made across the terminal markets served by Florida, it may still be possible to generate inferences about whether Florida charges supracompetitive prices in some markets.

Estimation

The switching regression model defined by equations (6), (7), and (8) was estimated using weekly price data for U.S. celery from 1985-1988. Shipping point price data were obtained for both California and Florida. All prices were in terms of dollars per crate. In California's case production is year around, but the producing area shifts seasonally. Thus, central coast prices were used during the summer and fall, and south coast prices were used in the winter and spring. The Florida analysis was based on data from Florida's mid Dec. to mid June production period.

Two main criteria were used in selecting terminal markets for inclusion in the study: (1) significance of the terminal as a receiver of celery, and (2) geographic location of the terminal. The five largest U.S. terminal markets are Boston, Chicago, Los Angeles, New York and San Francisco. These five markets were used to study California celery flows. Florida does not ship celery to the west coast, so the analysis for Florida shipments was limited to Chicago, Boston, and Atlanta, with Atlanta's inclusion based on obvious geographic considerations.

Results from the maximum likelihood estimation are summarized in Tables 1 and 2 for California and Florida, respectively. Considering the California analysis first, we note that most of the estimated coefficients are statistically significant. The probability, $1-\hat{\lambda}_1-\hat{\lambda}_2$, of efficient arbitrage is greatest, not surprisingly, in Los Angeles and San Francisco, those cities nearest the production regions. In all cases, however, the $\hat{\lambda}_i$ are either individually or jointly significant causing us to reject formally the hypothesis that arbitrage is efficient or that the law of one price holds for all t. (Joint significance of the $\hat{\lambda}_i$ for Boston was established based upon the usual likelihood ratio test.)

The fact that arbitrage is less likely to be efficient in the Eastern markets is quite consistent with prevailing views on pricing efficiency (Buccola 1983, 1985). For example, the risk in making unconsigned shipments likely increases with the shipment distance due to time lags, possible loss in quality, etc. Quantity and quality of information on market conditions may also decline as a function of distance between shipping point and receiving point.

Particularly relevant are the comparative magnitudes of the $\hat{\lambda}_i$. In each of the markets studied $\hat{\lambda}_1 > \hat{\lambda}_2$. Thus, each of these major terminals was more often characterized by relative undersupply than oversupply of celery, and no support is found for the Berger et al. conjecture that California causes market gluts in the eastern markets.

The estimates of mean transportation costs in Table 1 are all highly significant. With one exception, Chicago, $\hat{t}_C^i$ is increasing in distance from the producing area. The Chicago result may signal relative inefficiencies in the Chicago-area transportation and marketing network. Also interesting to note is the significant portion of wholesale celery prices that is due to shipment costs. This figure ranges from 28 percent in Los Angeles to 46 percent in Chicago, based on mean 1985-88 wholesale prices.

The results for Florida celery in Table 2 must be interpreted cautiously for the reasons indicated above. Florida annually supplies a very small portion of Chigago's celery (an average 2.4 percent over 1985-88) and has no obvious transportation cost advantage over California in serving Chicago. Thus, it can safely be assumed that Florida is a perfect competitor in this market. The estimated probability of efficient arbitrage for Florida celery in the Chicago market is 0.37, and $\hat{\lambda}_2 > \hat{\lambda}_1$. Thus, even though Florida celery marketing is much more coordinated relative to California, the probability of inefficient arbitrage is still significant. Interestingly, Florida's departures from efficiency seem biased towards producing relative market gluts.

Florida is a more significant player in the Boston market (26.8 percent of fresh market sales over 1985-1988), and comparison of Tables 1 and 2 shows that Florida has at least a $2.50 per crate advantage on shipment costs over California. (We we do not reject a priori that $\hat{t}_F$ for Boston may include some markup above the competitive price.)

The most interesting facet of the Florida analysis is comparison of the Boston and Atlanta markets. Florida is the dominant seller in Atlanta during the winter. In fact, during some weeks, there may be no California shipments at all. Although Boston is roughly 900 miles farther from the Florida producing regions than Atlanta, our estimates of the T_F^i suggest that shipment costs per crate are actually $.43 <u>less</u> for Boston than Atlanta. This result is evidence that Florida celery is being sold at supra competitive prices in Atlanta.

Conclusions

This paper has extended Spiller and Huang's methodology to test market integration and applied it in an agricultural markets setting. The prototype SH model applies to regions with indiginous supply sources. SH assume that efficient, competitive arbitrage will occur whenever autarkic prices differ by more than interregional transaction costs. Thus, regimes in the SH model are (1) autarky and (2) binding arbitrage.

The extension proposed in this paper was to regions known to be linked in trade, specifically the common situation in agriculture of one or a few localized production areas. When perfect competition in product allocation can be safely assumed, this extended model allows for tests of three regimes: (1) efficient arbitrage (i.e., the law of one price), (2) relative shortage, and (3) relative glut.

Results from application of the extended model to celery marketing indicated that California shipments in all cases departed significantly from the perfect arbitrage condition. However, no evidence was found to support the hypothesized eastern market glut scenario. Florida, despite having more coordinated marketing that its western rival, experienced similar problems in attaining efficient arbitrage.

Comparison of results for the Boston and Atlanta markets suggests, however, that Florida was successful in exploiting its relative market power in the Atlanta market. Although Kilmer and Taylor may be correct that Florida on average does not raise celery prices above the competitive level, this fact will provide little consolation for Atlanteans as they they sip their expensive Bloody Marys.

Table 1. Parameter Estimates: California Celery

	LA	SF	CH	BN	NY
T	2.37	3.83	5.45	4.83	4.53
	(23.50)	(32.07)	(14.96)	(2.53)	(6.44)
σ_v^2	0.57	1.27	0.33	0.88	1.05
	(4.26)	(5.39)	(0.82)	(1.40)	(1.92)
σ_u^2	3.54	7.93	2.21	2.62	3.51
	(2.92)	(2.43)	(4.46)	(1.28)	(3.59)
λ_1	0.16	0.12	0.55	0.78	0.62
	(1.99)	(1.88)	(2.64)	(0.71)	(1.41)
λ_2	0.11	0.05	0.27	0.04	0.03
	(2.09)	(1.38)	(2.36)	(0.39)	(0.90)
$1-\lambda_1-\lambda_2$	0.73	0.83	0.18	0.18	0.35
N	209	209	209	209	209
T as a Pct. of Mean P	28	38	46	41	40

Table 2. Parameter Estimates for Florida Celery

	CH	BN	AT
T	4.58	2.33	2.76
	(12.71)	(11.85)	(17.09)
σ_v^2	0.37	0.30	0.16
	(1.17)	(1.33)	(1.61)
σ_u^2	2.88	2.09	1.88
	(2.55)	(3.35)	(3.48)
λ_1	0.06	0.23	0.16
	(0.95)	(2.31)	(2.39)
λ_2	0.57	0.33	0.49
	(2.04)	(2.09)	(3.23)
$1-\lambda_1-\lambda_2$	0.37	0.44	0.35
N	48	111	116
T as a Pct. of Mean P	41	45	29

References

Berger, L., T. Hebert, D. Ricks, and J. Shaffer. "The U.S. Celery Production and Marketing Subsector: An Evaluation of Market Coordination and Performance." Agricultural Economics Report No. 517, Department of Agricultural Economics, Michigan State University, October 1988.

Buccola, S.T. "Risk Preferences and Short-Run Pricing Efficiency." *American Journal of Agricultural Economics*. 65:(1983): 587-91.

______. "Pricing Efficiency in Centralized and Noncentralized Markets." *American Journal of Agricultural Economics*. 67(1985): 583-90.

Carter, C.A. and N.A. Hamilton. "Wheat Inputs and the Law of One Price." *Agribusiness*. 5(1989): 489-96.

Goodwin, B.K. and T.C. Schroeder. "Testing Perfect Spatial Market Integration: An Application to Regional U.S. Cattle Markets." *North Central Journal of Agricultural Economics*. 12(1990): in press.

Goodwin, B.K., T.J. Grennes, and M.K. Wohlgenant. "A Revised Test of The Law of One Price Using Rational Price Expectations." *American Journal of Agricultural Economics*. 72(1990): in press.

Horowitz, I. "Market Definition in Antitrust Analysis: A Regression-based Approach." *Southern Economic Journal*. 48(1981): 1-16.

Houck, J.P. "Market: A Definition for Teaching." *Western Journal of Agricultural Economics*. 9(1984): 353-56.

Ippolito, R.A. and R.T. Masson. "The Social Cost of Government Regulation of Milk." *Journal of Law and Economics*. 21(1978): 33-65.

Kilmer, R.L. "A Review of the Current Pricing Systems of Celery, Sweet Corn, and Potatoes." Economic Information Report 171, Food and Resource Economics Department, University of Florida, November 1982.

Ravillion, M. "Testing Market Integration." *American Journal of Agricultural Economics.* 68(1986): 102-9.

Richardson, D.J. "Some Empirical Evidence on Commodity Arbitrage and The Law of One Price." *Journal of International Economics.* 8(1978): 341-51.

Shepard, L. "Cartelization of the California-Arizona Orange Industry, 1934-1981." *Journal of Law and Economics.* 29(1986): 83-123.

Shonkwiler, J.S. and E. Pagoulatos. "A Model of Weekly Price Discovery for Florida Celery." *Southern Journal of Agricultural Economics.* 12(1980): 113-8.

Spiller, P.T. and C.J. Huang. "On the Extent of The Market: Wholesale Gasoline in the Northeastern United States." *Journal of Industrial Economics.* 34(1986): 131-45.

Stigler, G.J. and R.A. Sherwin. "The Extent of The Market." *Journal of Law and Economics.* 37(1985): 555-85.

Taylor, T.G. and R.L. Kilmer. "An Analysis of Market Structure and Pricing in the Florida Celery Industry." *Southern Journal of Agricultural Economics.* 20(1988): 35-43.