Simulation

ADAPTATIONS OF REACTIVE PROGRAMMING IN SPATIAL AND TEMPORAL SIMULATION ANALYSIS

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This paper reviews some of the conceptual and practical problems which have arisen in the application of reactive programming to spatial and temporal studies of Northwest agriculture. It suggests that while reactive programming has passed the test as an effective tool for applied research, its potential and its limitations are not yet fully understood.

CONCEPTUAL PROBLEMS

Although developed by Tramel and Seale in 1959, reactive programming has had a long and frustrating climb to acceptance among economists. Tramel's untimely death and Seale's transfer to other duties prevented the full exploitation of the algorithm by its developers. While Takayama and Judge's questioning of its convergence properties in 1963 received wide circulation, Tramel's 1965 rebuttal did not. King in his book with Bressler, and in two 1972 publications with Ho did much to restore the credibility of the algorithm and to add refinements which increased its versatility.

Many researchers in recent years have reported successful application of the reactive programming algorithm in interregional and intertemporal studies, using either the Tramel and Seale or the King and Ho programs (Levins and Langham, O'Rourke and Casavant, Summers, Zusman et al., Riley and Blakley, Hurt, Ikerd, Pendse and Youde, Goodwin, Brown and Elrod, etc.).

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While these studies have wrestled with the usual problems of specifying demand, supply and transfer functions, they have not confronted the two scientific questions which still remain, (a) the general relationship between reactive programming and quadratic programming originally raised by Takayama and Judge and (b) specifically, the convergence properties of reactive programming. Tramel, in his 1965 defense pointed out that "Quadratic programming as presented by Hildreth is a generalized procedure for solving programming problems involving quadratic objective functions with the type of spatial equilibrium problem under discussion being a special case. Reactive programming is a generalized procedure for solving spatial equilibrium problems with the type of problem under discussion being a special case." King and Ho demonstrated that selected problems originally solved by quadratic programming could be more economically solved by reactive programming. In addition, as Zusman et al. point out, quadratic programming requires the somewhat restrictive assumption that the cross derivatives be symmetric. In terms of general properties, one can say that reactive programming is especially appropriate for spatial equilibrium problems. It has lower input requirements and greater flexibility of functional forms than quadratic programming. However, in other types of problems, the researcher cannot reply on such readymade rankings, but must choose the algorithm most appropriate to his study objectives.

The issue of convergence is much more critical. An algorithm may converge too slowly (the Takayama-Judge criticism), converge to a local but not a global solution, or fail to converge. The Takayama-Judge criticism and the failure to converge criticism have been effectively silenced by the many successful applications of reactive programming. There is a priori reason to belive that the market simulating approach of reactive programming (where each supplying region in turn adjusts its shipments according to market experience) will lead to convergence. However, the full convergence properties have not yet been analyzed. Tramel claimed that reactive programming was equivalent to the "Hildreth process" which can be shown to converge. However, Zusman et al. point out that this applies only for cases where the equivalence with an extremum problem is valid. In the case where the cross derivatives are symmetric, Zusman et al. show that when the conditions for local stability are satisfied, global stability is satisfied and convergence is assured. Local stability will occur when the matrix of the price demand coefficients is negative quasi-definite for all markets, and the matrix of the price supply coefficients is positive quasi-definite for all supply regions.

APPLICATIONS TO NORTHWEST AGRICULTURE

Summers first recognized the pertinence of the reactive programming algorithm to the spatial problems of Northwest fruits and vegetables. Northwest states have become dominant suppliers of fresh produce such as, Idaho potatoes, Washington apples and Northwest sweet cherries, despite their distance from major markets. However, returns are susceptible to increased competition from suppliers located close to major markets, and to increases in costs of transportation and storage, all factors which can be easily studied in the reactive programming framework. Summers looked at interregional and intertemporal competition in potatoes. The present author has been involved in studies of fresh sweet cherries and fresh apples from which most of the subsequent discussion will be drawn (O'Rourke and Casavant 1974, O'Rourke 1975).

Production of sweet cherries is highly localized and highly seasonal. About one-third of all fresh supplies come from California, most of the remainder from Washington, Oregon, Idaho, Utah and Montana. Harvest in each district lasts only 3-4 weeks, beginning in California in May and in Montana and the higher elevations of Washington in late-July. Shipments are erratic throughout the season as different districts reach peak volume. However, aggregate supply usually has two major peaks, in early June when California is almost the sole supplier and in early July when Northwest shipments are greatest. A poorly developed processed market in the Northwest assures that all sweet cherries which meet U.S. No. 1 standards tend to be shipped fresh. Our study sought to explore, (a) the most profitable distribution of the U.S. fresh sweet cherry crops, (b) potential for storing some of peak period shipments for sale in a later period, (c) the relative efficiency of current marketing efforts and (d) the potential impact of alternative marketing strategies.

The base year used in the study was 1971, when record crops in both California and the Northwest with considerable overlap of shipments caused market gluts and depressed prices. The season was divided into five time periods: I Pre-June 15, II June 16-30, III July 1-15, IV July 16-30, V Post July 31. Supply and average wholesale price tended to be inversely related, with some lag apparent between time of peak shipments and time of lowest wholesale market price (figure 1). The decision was made to estimate

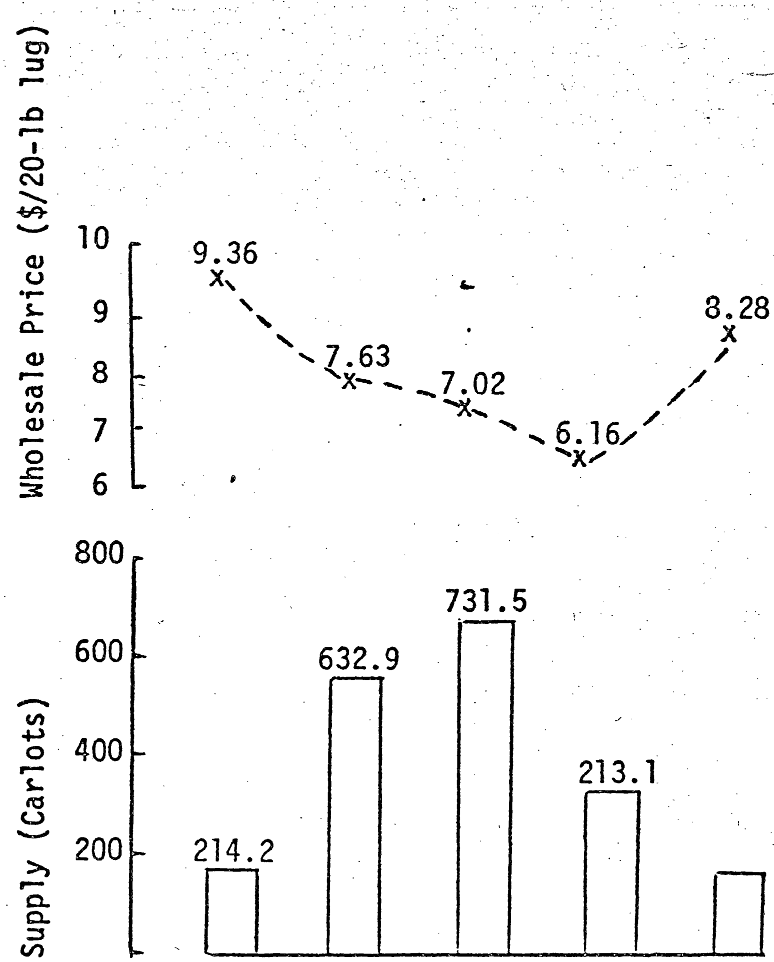

Figure 1. Supplies and average wholesale price of sweet cherries in 15 selected cities by time period, 1971 season

actual wholesale demand relations for 15 major markets accounting for almost two-thirds of 1971 fresh sweet cherry shipments, rather than to synthesize demand curves by region as has been done in other studies (Summers, Levins, etc.). Supplies were assumed fixed at the actual levels shipped to these cities in 1971. Freight rates were obtained from appropriate shipping organizations. A wholesale markup of $1/20 lb lug was assumed. Since no cost of storage data were available, this cost was varied in separate runs of the model from 10¢ to 50¢/20 lb lug. The solution thus maximized net returns to the fresh sweet cherry industry at shipping point.

The original formulation of the model contained 5 time periods, 7 supply regions (northcentral and southcentral Washington were treated separately) and 15 markets, giving an input matrix of 35 x 75 dimensions. However, since prices in period III were under all circumstances below those in period II, and period II prices below those in period I, no storage would occur in the first 2 periods. Accordingly, periods I and II could be run as separate spatial problems. Since intertemporal linkages could exist between period III and subsequent periods, the scale of the problem was reduced to 21 x 45. Similar situations are likely to prevail for perishable produce and other highly seasonal items.

The results suggested that the fresh sweet cherry industry could greatly improve net returns at shipping point by improved spatial and temporal allocation of a given crop. Smaller and off-peak suppliers could improve their returns by being more selective in the markets served. (There was a tendency for all suppliers to try to serve all markets). The largest peak suppliers, notably Washington, would be forced to serve many markets but could benefit from storing part of peak supplies from 2 to 4 weeks. At a storage cost of 10¢/lug per period it would have benefited the industry in 1971 to store 14.7% of period III production for 2 weeks and 13.4% for 4 weeks and to store 20.6% of period IV production for 2 weeks. At a storage cost of 50¢/lug, it would be economical to store only 3% of period III production for 4 weeks. Further problems with storage are that the benefits accrue to all peak shippers whether or not they undertake the costs and risk of storage, while as a result of storage late season price is lowered for all late season suppliers.

If one defines the efficient marketing system as the equilibrium solution of reactive programming, then deviations from that solution can be used to measure changes in efficiency. The optimal solution for 1971 suggests that a 1.9% increase in transfer costs (freight rates, storage costs and wholesale markup) could generate a 20.6% increase in net returns to producing regions. Not all regions could achieve this level of efficiency gain but all could receive some benefits.

The problem was also analyzed for fixed supplies 20% above 1971 levels and for both a 50% increase and a 25% decrease in freight rates. The larger supplies could be handled with only a 6% price decline by making the greatest absolute sales increases in larger markets and the greatest percentage increases in smaller markets. A 50% increase in freight rates would lead to a 17.7% increase in total transfer costs but only a 4.5% average reduction in producing area returns. Conversely, a 25% reduction in freight rates such as might occur where backhaul is available (Pendse and Youde) reduced total transfer costs by 8.9% and increased production area returns by 2.2%. Since all supplying regions were similarly affected by the higher freight rates, the overall allocation of supplies was little affected by changes in freight rates.

The structure of competition in fresh apples is quite different from that in sweet cherries. Apples are produced commercially in 37 states, almost all of them nearer to major markets than Northwest producers. In addition, shipments from Canada and from Southern hemisphere sources are directly competitive in many U.S. markets. Apples are now sold for 12 months of the year. While there have been a number of attempts to look at intra-seasonal demand for apples (Price, Pasour, Ben-David, Kenyon, Moffett, et al.) no consensus has been reached on identifiable seasons. Accordingly, for the purposes of our analysis, we divided the year into 4 equal periods of three months beginning in October. For our base year we used 1969-70, a year of record national supplies. As in the case of sweet cherries, supplies were assumed fixed at 1969 levels, with 90% of the total becoming available in the October-December quarter, about 10% (mostly Summer apples) becoming available in the July-September quarter. Preliminary runs suggested that nearby minor producing areas could be aggregated into producing regions without distorting program results. In all sixteen producing regions including Canada and other imports were defined. Demand was estimated at the retail level for 26 major cities accounting for over 40% of all U.S. fresh apple supplies in 1969. Fixed marketing margins were used to derive demand curves at the retail buying level. The dimensions of the problem were thus 64 x 104, the largest reactive programming problem reported to date. A transfer cost matrix of similar dimensions was constructed using a distance-related transportation function and the author's estimates of storage costs (O'Rourke).

The core requirements of the problem on an IBM 360/67 computer were 232K. The size of the problem itself created difficulties. For example, using the King and Ho initial equilibrium price option, when the algorithm did not complete an initial iteration, the only means to identify the cause of the holdup was a hand search through the input data. Alternatively, using the Tramel-Seale option of specifying initial demand equal to supplies, rounding errors due to the computer's conversion of input data to an exponential base and reconversion to the decimal system led the market supplies and demands to become unequal. Again, because of the size of the problem, the nearer the final solution lay to the initial specification of market allocation, the more rapidly a final solution could be reached. It may be computationally more efficient (especially where transfer costs differ widely) to use the optimal solution from a prior run as the basis for the initial specification of market allocation rather than the King and Ho price equilibrium option. A further problem noted with the price equilibrium option arose when the quantity demanded at the initial equilibrium price was negative in a given market, and the program terminated. One could avoid the problem by dropping that market. However, in a number of cases, when transfer costs were taken into account, that market would be included in the final solution. Clearly, the initial equilibrium price option must be used with discretion.

Reactive programming provides an option of examining two products simultaneously. The evidence is strong that demand for Washington apples is differentiated from that of other apples (Edman, Harrington). However, specification of separate demand functions for each market and time period was not feasible because of lack of data and because it would have led to a problem exceeding the core capacity of the computer. On the assumption that the demand functions for Washington apples and other apples in each market have the same slope but different intercepts, a reduction in transfer cost for Washington apples will have the same impact on trade flows in the final solution as a market price premium. Washington apple price premiums were estimated for each city from the limited data available and used to derive adjusted transfer costs. Final output of the reactive program was, of course, adjusted to restore the balance of Washington transfer costs and the market price premium.

Various runs of the model suggested that the U.S. fresh apple industry could have marketed 13.2% more fruit in the 26 markets studied at a 10% higher FOB price than for the record 1969-70 crop, by more late season marketing and by greater sales in the major Southern and Southeastern markets. A 50% increase in transportation rates would have led to a 13% increase in total transfer costs and an average 5.2% reduction in FOB price. However, the regions most distant from major markets would have suffered curtailed shipping zones and above average reductions in FOB price. The allocation over time altered little. In was clear from the results for Washington state that in the face of higher freight rates, its price premium would become even more critical in gaining its products access to distant markets.

A feature of reactive programming solutions as of most standard programming algorithms is that the optimal solution tends to show fewer active routes than real world experience, partly because such issues as risk aversion, varietal differences, customary trade patterns, etc. are not explicitly considered (table 2). For example, in the apple model, for 16 supplying regions, the final solution showed only 49 active routes of a possible 416 routes. Eight supplying regions supplied only one market each. While the actual trade flows for 1969-70 showed 271 active routes, each region did tend to concentrate on one or two markets. A critical issue is whether reactive programming is sensitive to the real competitive advantages of supplying regions in given markets or gives a final solution which would be greatly perturbed by rather minor changes in the demand, supply or transportation parameters.

Evidence from the full 64 x 104 apple model suggests that major changes in total supply or in transportation costs alter the optimal allocation materially only in directions which would have been predicted from basic location theory. For example, with higher transportation rates, Washington tends to lose its more distant markets. However, a change in the percentage distribution of supplies by region (i.e., a major change in the competitive situation) does cause major changes in the volume and direction of trade flows.

FURTHER SENSITIVITY ANALYSIS

To facilitate further sensitivity analysis, the apple model was reformulated on a total season basis, thus reducing the problem to its spatial aspects and to 16 x 26 dimensions. Variations tested were:

(a) the original 1969-70 supply, demand and transfer relations,

(b) a 10% increase in the absolute size of the quantity coefficients for 5 Northeastern markets, New York, Chicago, Philadelphia, Detroit and Cleveland,

(c) a 10% decrease in the absolute size of the intercept terms for the same cities,

(d) a 20% increase in supplies of all Eastern regions only,

(e) a 20% increase in supplies of Central regions only.

(f) a 20% increase in supplies from Washington's western competitors, California, Oregon and Idaho only.

The results were consistent with theoretical expectations and in general showed only minor and gradual changes (table 1). For example, Cases (e) and (f), involve approximately the same increase in aggregate supply arising in different areas but yield identical prices and shipping costs. In general, reactive programming assures that reductions or increases in prices are felt fairly uniformly throughout the system. In the real world, lack of information and other rigidities might tend to concentrate such effects more on the regions which caused the increased supply. The number and choice of active routes was insensitive to parameter changes. The level of activity on a given route was more sensitive. For example, the lower intercept term in Detroit caused its main supplier, Michigan, to decrease shipments by 25% and to transfer additional supplies to Minneapolis, St. Louis and New Orleans. Clearly, one cannot interpret the detailed trade flows too precisely unless one has greater faith in the accuracy of the demand, supply and transfer relations than data normally permits or assurances that factors not included in the model have a negligible influence.

A problem has arisen in extension use of reactive programming as a didactic tool because the optimal solution assumes that all regions will rationally seek a market equilibrium which maximizes aggregate net returns. Perhaps of more direct use to industry users is how their region should behave assuming all other regions follow customary (and presumably nonoptimal) marketing strategies. To examine this issue further, the demand curve in each city was adjusted for the supplies actually shipped from regions other than Washington in 1969-70. Washington was then allowed to maximize its net

Table 1. Reactive programming apple model sensitivity analysis

Variation	Quantity supplied	Producer Returns		Retailer buying price	Average shipping cost	Active routes
		Price	Value			
	(1000 boxes)	($/box)	($/m)	($/box)	($/box)	(no.)
(a)	38,360	4.75	182.4	5.15	.40	41
(b)	38,360	4.68	179.4	5.08	.41	41
(c)	38,360	4.52	173.3	4.93	.40	41
(d)	40,860	4.60	188.1	5.02	.42	41
(e)	39,324	4.70	184.7	5.10	.40	40
(f)	39,320	4.70	184.7	5.10	.40	40

revenue. Its FOB price would have been 2.2% lower than in the situation where all regions pursued optimizing goals. It was notable, however that the trade flows from Washington were much more similar to actual experience than under the situation where all regions were assumed to be optimizers (table 2). It would appear that the marketing decisions of Washington shippers were rational given the behavior of competing suppliers.

CONCLUSIONS

Reactive programming's value as a versatile tool for spatial equilibrium problems has become more widely recognized in recent years. Some conceptual questions still remain unanswered. It is hoped that subsequent applications and adaptations will explore the full theoretical and empirical potential of the model.

Table 2. Washington apple shipments by market under alternative decision rules, 1969-70 supplies

Market	Actual	All Regions optimizing	Washington Alone optimizing
		(1000 boxes)	
Boston	263.3	--	--
Buffalo	58.0	--	--
New York	1892.1	4294.9	1612.5
Philadelphia	528.0	--	331.7
Baltimore	160.0	--	397.0
Washington, D.C.	262.8	--	62.1
Pittsburgh	270.6	--	--
Detroit	620.8	--	--
Cleveland	552.6	--	1932.3
Cincinnati	402.6	--	53.6
Chicago	1084.4	2082.9	615.6
Milwaukee	163.9	347.0	164.8
Minn - St. Paul	507.6	--	412.1
St. Louis	528.5	--	254.2
Kansas City	325.6	--	46.6
Louisville	179.8	--	--
Atlanta	350.2	--	154.3
Birmingham	254.5	--	--
New Orleans	548.5	--	355.5
Houston	541.5	1474.2	1124.2
Dallas	598.0	1665.4	1216.8
Denver	502.3	--	272.9
Los Angeles	3336.3	5773.7	4832.2
San Francisco	1028.9	331.8	1038.4
Portland	177.2	--	145.1
Seattle	827.9	--	948.0
TOTAL	15,966.0	15,969.9	15,969.9

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