The CARD Linear Programming Model of U.S. Agriculture

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The Center for Agriculture and Rural Development (CARD) at Iowa State University, Ames, and the U S Department of Agriculture's (USDA) Economic Research Service have invested considerable effort in developing a national database for modeling resource use in U S farming The CARD linear programming (LP) modeling system has been used to assess the Resources Conservation Act (RCA) (*8*), and to analyze the effects of enrolling acreage in the conservation reserve (*7, 9*) [1] Recently, the model was used to determine the cost of conservation compliance once enrollment in the conservation reserve was complete (*3*) This modeling system remains a primary instrument for assessing the link between land use and aggregate U S agricultural output Since a typical CARD model is very large (at its most detailed level, the model has 105 producing regions, 8 land groups, 330 crop rotations, and 12 tillage alternatives), many of its underlying economic properties are difficult to assess The purpose of this paper is to shed some light on these properties

We focus particular attention on a CARD LP's response to changing relative input prices The resulting derived demand elasticities provide a measure of input substitutability in the model Possibilities for input substitution, in turn, affect the way the LP model responds to increases in output levels and changing resource endowments The greater the potential for input substitution, the more slowly marginal costs rise as agricultural output increases

Model Description

The model that we have chosen to analyze is a reduced version of the full CARD-RCA model of cost minimization for U S crop production (*4*) We reduced the size of this LP by aggregating up from 105 producing areas to the 31 market regions shown in figure 1 The number of tillage options was also reduced to the three major alternatives conventional-, minimum-, and no-tillage These simplifications make the construction of useful summary elasticities feasible without substantially altering the shape of the model's aggregate isoquants Even after these reductions, over 13,000 alternative crop production activities remain in this model

National commodity demands for wheat, feed grains, cotton, soybeans, corn silage, sorghum silage, legume hay, and nonlegume hay, as well as resource endowments, are fixed in this problem [2] Resource endowments are expressed in terms of dryland and irrigated acreage (by land class) Water supplies for existing irrigated acreage may be purchased at an exogenously determined price [3] The remaining variable inputs include labor, machinery, nitrogen, pesticides, and "other "[4]

To illustrate why it is important to analyze the role of input prices in this model, we increased a selected price, in this case machinery, by 25 percent (holding all other prices and outputs constant) Table 1 shows the resulting reallocation of soybean, wheat, and corn outputs A total of 88 million bushels of soybeans and 91 million bushels of wheat shifted among regions Corn production rose by 241 million bushels Because the geographic location of production is an important determinant of resource depletion, the postulated change in machinery price can be expected to affect both regional and national projections of such target variables as erosion

Analysis of Aggregate Demands

We used the summary function algorithm in (*5*) to analyze the response of the LP model to input price changes This algorithm involves two steps First, we obtained the optimal LP response surface (as a function of prices) for the CARD model in a prespecified set of price directions The sample design was orthogonal,

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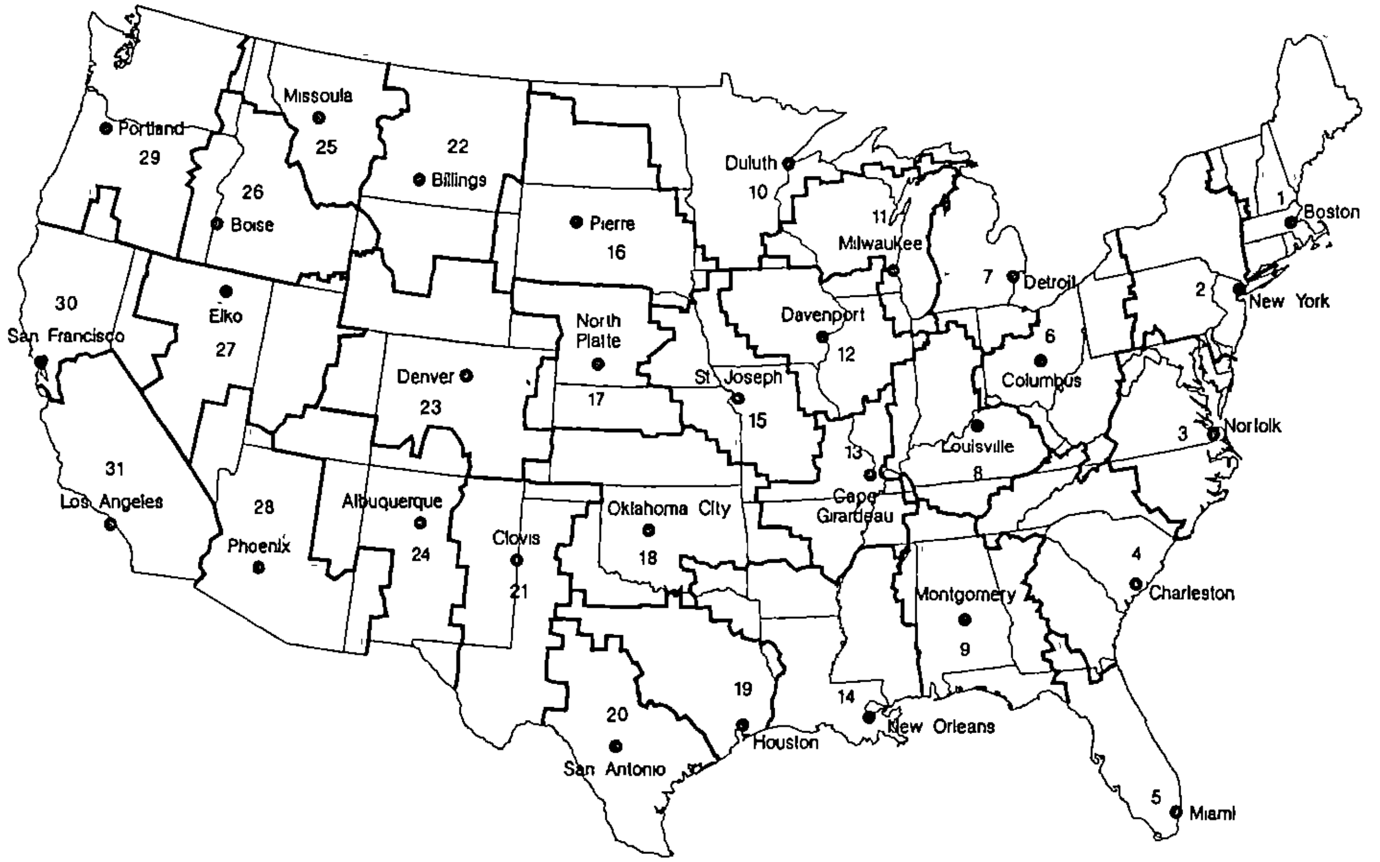
[1] Italicized numbers in parentheses cite sources listed in the References section at the end of this article

[2] Quantities demanded and resource endowments represent estimates for the year 2000 These were developed for use in USDA's recent RCA analysis (*2*)

[3] Base prices represent 1978 estimates Additional detail on their construction is provided in (*2*)

[4] Throughout this article, the prices of inputs in this residual category will always be moved together, legitimizing their aggregation into a single group

Figure 1
The 31 market regions in the CARD LP model



with each price varying independently over the 75-125 percent range of the base value for each of the six input groups Using a dynamic sampling procedure that takes account of the unique properties of a linear program, we derived an acceptable piecewise linear approximation after 53 solutions of the model In the second step of the algorithm, we fit a translog cost function to the piecewise linear summary (Actually, it was the system of cost share equations which were fitted) This step allowed for computation of derived demand elasticities at the base point, which is also the point of approximation for the translog summary function

Table 2 presents the national, output-constant price elasticities of input demand produced by this algorithm All of the on-diagonal elements are negative, as expected, and there is only one complementary relationship, that between labor and machinery However, with the exception of water, national input use in this model is highly price-inelastic, particularly when compared with the evidence based on econometric cost functions for U S agriculture (*1, 6*) [5]

The relatively small elasticities in table 2 indicate that, despite the large number of activities in the model, factor intensities vary little (Water is an exception because both dryland and irrigation alternatives exist in the model) Figure 2 depicts the situation for the case of two inputs, X_1 and X_2 The rays A,

[5]This absence of substitutability is even more striking when one notes that these aggregate elasticities include both intraregional and interregional substitution possibilities

Table 1—Regional shifts in the production of corn, soybeans, and wheat in response to a 25-percent increase in the price of machinery

Crop and market region	Change in output
	Million bushels
Soybeans	
8 (Louisville)	15
9 (Montgomery)	37
11 (Milwaukee)	8
13 (Cape Girardeau)	28
14 (New Orleans)	-11
15 (St Joseph)	-44
17 (North Platte)	-33
Net change in production	0
Wheat	
5 (Miami)	1
9 (Montgomery)	-43
11 (Milwaukee)	-7
12 (Davenport)	17
13 (Cape Girardeau)	-32
15 (St Joseph)	-9
17 (North Platte)	34
22 (Billings)	34
25 (Missoula)	4
26 (Boise)	1
Net change in production	0
Corn	
11 (Milwaukee)	25
14 (New Orleans)	33
15 (St Joseph)	-22
16 (Pierre)	112
17 (North Platte)	93
Net change in production[1]	241

[1]Since the national demand constraint is specified in terms of total feed grains output, there can be changes in the mix of feed grains produced In this case, corn production increases slightly at the expense of other feed grains This added flexibility leads us to overstate the model's true output-constant input demand elastiticites

Table 2—National derived demand elasticities (output constant)[1]

Inputs	Labor	Machinery	Nitrogen	Pesticides	Water	Other
Labor	-0 04	-0 04	0	0 02	0 02	0 03
Machinery	- 01	- 04	01	03	01	01
Nitrogen	0	02	- 06	0	01	03
Pesticides	02	08	00	- 12	01	01
Water	11	32	11	11	- 82	17
Other	01	01	01	01	01	- 04

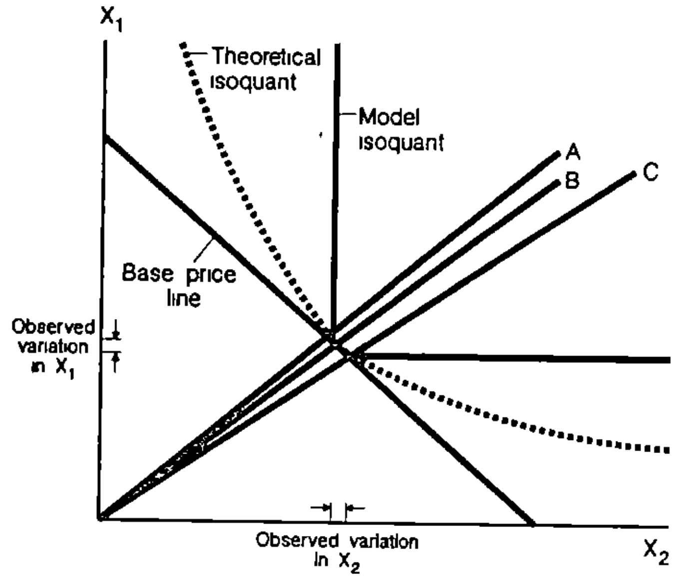
[1]Since the national demand constraint is specified in terms of total feed grains output, there can be changes in the mix of feed grains produced This added flexibility leads us to overstate the model's true output constant input demand elasticities

B, and C represent alternative activities in the production of a given crop These alternatives might involve different regions, different land types, or different rotation/tillage practices When combined, they produce the model isoquant (fig 2) As long as relative prices remain on the base price line, the description of what we believe to be the true underlying technology (theoretical isoquant) will be reasonably accurate As a result, the model should reproduce the actual outcomes fairly well This model, however, does not appear to be capable of capturing the effect of input price changes which might induce substantially different factor intensities

Alternative technologies, some of which are not employed at current prices, would have to be introduced into the CARD model to broaden the range of input intensities Increased factor substitution would reduce the rate of increase in production costs resulting from a given input price increase, reducing production shifts among regions in response to a given factor price change By omitting these alternative technologies, the CARD model tends to overstate the amount of regional shifting when a new configuration of output and input prices is specified Whether this leads to an exaggeration or understatement of, say, total erosion is unclear That depends on the model's cost-minimizing response to a particular scenario What is clear is that the allocation of production, and hence erosion, among the various regions will not be correctly predicted, if regional production shifting is not correctly restricted

Figure 2

Substitutability of nonwater inputs in the model



X_1 and X_2 are two agricultural inputs and A, B and C represent linear activities in the LP model

Conclusions

The CARD LP model has the attribute of yielding very detailed geographical information on the use of resources in U S agriculture This explains its popularity in policy analysis of land use problems National factor demands (except water) in this model, however, are very unresponsive to relative input price changes, probably because the LP activities associated with alternative production locations, rotations, and tillage options tend to provide only a small range of input-output ratios These ratios, which reflect base period intensities, permit the model to replicate patterns of production and input use in that period However, when confronted by changes in relative input prices, the model fails to account for alternative activities that would permit anticipated input substitution

Yet, the model as a whole is not unresponsive to changes in relative factor prices A 25-percent change in the relative price of machinery induces many interregional production shifts This is a direct consequence of the limited potential for substitution among inputs in any given region Farmers in a marginal region will actually substitute other inputs for the more costly machinery This enables them to keep cost increases down, thus limiting the amount of displaced production Our analysis shows that by limiting the potential for such input substitution, and allowing unrestricted regional production shift, the model overstates the magnitude of regional shifts in production This limitation reduces the model's potential for projecting input and output levels at both the regional and national levels

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