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USING AN IO-LP MODEL TO EVALUATE THE IMPACTS OF ETHANOL PRODUCTION IN THE STATE OF IOWA

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Introduction

Title 2-A of the Energy Security Act of 1980 (P.L. 96-294) directs the Secretary of Agriculture and the Secretary of Energy to develop and implement a plan to achieve a total level of fuel alcohol production and use within the United States of at least 920 million gallons per year by December 31, 1982. Much of the fuel alcohol is likely to be produced in the state of Iowa by using corn as the main raw material for the production of ethanol (grain alcohol).

Adding or expanding an ethanol production industry in Iowa can have significant impacts on the state's economy because of the construction and set-up of the production plants and operation of the industry after the plants have been set up. The construction of ethanol plants will increase the output of the construction industry and other industries providing equipment, engineering services, and other construction support. Plant construction also will have an impact on the capital and labor markets. Ethanol production, after completion of the plants, will require numerous production inputs such as capital, land resources, energy, labor, transportation services, corn, and chemicals for the milling process. The production, thus, will have impacts on the industry sectors which provide these inputs. The by-products of ethanol production include gluten feed and gluten meal which can be substituted for soybean meal in livestock feed. The appearance of the by-products, thus, may affect soybean production and use by the livestock sector, as well as the prepared feeds industry.

An evaluation tool is needed to assess these interrelated impacts. It is believed that an input-output linear programming (IO-LP) model, which links an input-output (IO) model with a linear programming (LP) model, can provide policymakers with comprehensive information to examine alternative production strategies in achieving maximum benefits and the least adverse effects to the state's economy. The IO structure in the IO-LP model relates the agricultural sector to other industrial sectors in the region. It can provide estimates of the direct and indirect effects of the ethanol production to various industry sectors. The LP structure facilitates linkage of the production technology between resource uses and outputs of agricultural and industrial sectors. It is useful in suggesting the most efficient combination of various resource uses to attain the production objectives.

The objective of this paper is to describe an Iowa IO-Lp model and use the model to examine the economic impacts of ethanol production in the state of Iowa. This paper presents only the impacts of the ethanol production after the production plant is in place. The impacts on industry sectors which supply the production inputs, and the industry sectors which are affected by the by-products of the ethanol production are investigated for three output levels of an ethanol industry in Iowa.

An Evaluation Tool: Iowa IO-LP Model

The Iowa IO-LP model has been designed to provide a relatively detailed representation of crop production, aggregate production of industries, and production interrelation between the agricultural and industrial outputs in Iowa. The Iowa model has an objective function which is specified as being the maximization of farm net income. The model also contains a set of constraints which specify restraints on crop production levels and industrial production activities. A schematic diagram of the Iowa IO-LP model is illustrated in Figure 1. The diagram has seven blocks of coefficients which have to be prepared. Block A is the Leontief's IO coefficients matrix; Block B is the cost coefficients vector; Block C is the commodity price coefficient vector; Block D is the final demand vector for the IO component; Block E is the yield coefficients vector for various crops; Block F is the resource supply vector, and Block G is the technical resource supply coefficients for agricultural and non-agricultural production. Basically, the Iowa IO-LP model is an agricultural production model for the state with an additional set of constraints describing the interrelations between agricultural and nonagricultural production in Iowa.

Objective Function

The objective function of the Iowa IO-LP model is defined to maximize the net returns from crop production.

The objective function is to maximize

$$\sum_{m}\sum_{n} P_{mn} Q_{mn} - \sum_{r}\sum_{k}\sum_{n} C_{rkn} Y_{rkn} \qquad (1)$$

where m = 1 to 7 for crop production. The seven crops are corn (=1), legume hay (=2), nonlegume hay (=3), oats (=4), sorghum (=5), soybeans (=6), and wheat (=7).

n = 1 to 12 for the producing areas.

r = 1 to 27 for possible crop production activities defined for

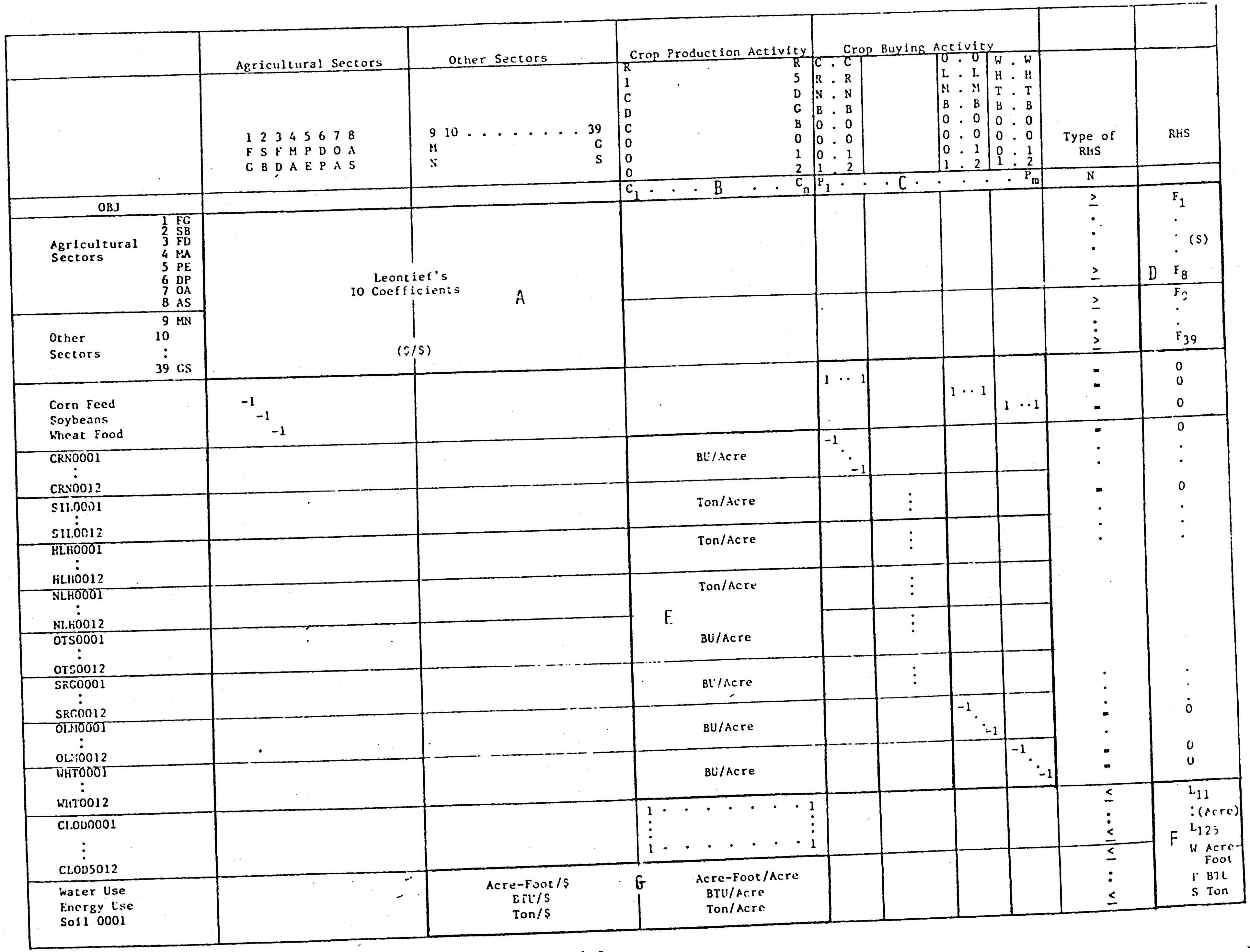

Figure 1. A schematic diagram of the Iowa IO-LP model

producing area n. Each activity is a combination of crop rotation, tillage method, and conservation practices.

k = 1 to 5 for land classes on which the crop is grown

P_{mn} is the selling price of the crop in dollars per bushel or tons of crop m produced in PA n.

C_{rkn} is the cost per acre in dollars per acre of production for production activity r on land class k in PA n.

Y_{rkn} is acres of land class k in PA n used for production activity r.

Q_{mn} is the quantity of crop m produced in PA n.

Maximization of net return from crop production is used mainly because later the model will be used to analyze policy issues related to agriculture. A different form of objective function can be defined according to a specific application.

Constraints

IO Constraints

The constraints specify input and output relationships among industries. The input-output relation is formulated as:

$$X_i - \sum_j a_{ij} X_j \geq F_i, \quad i = 1 \text{ to } 38 \text{ and } j = 1 \text{ to } 38 \qquad (2)$$

Where X_i (or X_j) is the total output in dollars from industry i (or j). a_{ij} is the amount of goods and services needed from industry i to produce one dollar of output of industry j (i.e., $a_{ij} = X_{ij} \div X_j$). F_i is the total final demand in dollars for the goods and services of industry i.

The relationship (2) can be stated as the total output from industry i after subtracting the intermediate demand (expressed as $\sum_j a_{ij}X_j$) is greater than or equal to the final demand for outputs of indistry i. Equation (2) consists of 38 inequalities, some of which may be formulated as:

$$X_i - \sum_j a_{ij}X_j \leq F_i, \text{ for some } i.$$

This formulation is used to examine whether the exogenously specified final demands can be relaized when production resources are limited.

Linkage Constraints

The crop production balance rows are one of linkage constraints. A balance row sums up the total amount of production of crop m in PA n.

The rows are formulated as

$$\sum_r \sum_k T_{rm} b_{rmkn} y_{rkn} = Q_{mn} \qquad m = 1 \text{ to } 7 \text{ and } n = 1 \text{ to } 12 \qquad (3)$$

Where b_{rmkn} is per acre yield of crop m defined in crop production activity r on land class k in PA n. T_{rm} is the rotation weight for crop m in production activity r. The crop production activity is uniquely defined by crop rotation and tillage conservation practices.

Three other constraints are used to link the total production values of feed grains to the feed grain industry sector; soybean production to the soybean industry sector; and wheat to the food grain industry sector.

The linkage for the feed grain sector can be expressed as

$$X_1 - \sum_n (P_{1n}Q_{1n} + P_{4n}Q_{4n} + P_{5n}Q_{5n}) = 0 \qquad (4)$$

The balance row indicates that total values of feed grain crops (corn, oats, and sorghum) are equal to the output (X_1) of the feed grain industry.

Similarly, the total output from the soybean industry (X_2) is equal to the value of the soybean crop expressed as

$$X_2 - \sum_n p_{6n}Q_{6n} = 0 \qquad (5)$$

and the total output from the food grain industry (X_3) is set to equal the value of the wheat grain production. That is

$$X_3 - \sum_n P_{7n} Q_{7n} = 0 \qquad (6)$$

Resource Constraints

Land, water, and energy are the major resources required for crop production as well as industrial production. The total cropland used has to be less than the total cropland available. Acres used by production activities on land class k in PA n has to be less than total supply L_{kn} of acres of land class k in PA n. That is,

$$\sum_r Y_{rkn} \geq L_{kn}, \qquad k = 1 \text{ to } 5 \text{ and } n = 1 \text{ to } 12. \qquad (7)$$

Also, water used by agriculture and industries cannot exceed the total water available in the state.

$$\sum_r \sum_k \sum_n w'_{rkn} Y_{rkn} + \sum w_j^0 X_j \leq W, \; j = 1 \text{ to } 38 \qquad (8)$$

where w'_{rkn} is gallons per acre used by activity r on land class k in PA n, w_j^0 is the gallons of water required for one dollar of output from industry j, and W is the total water in acre-feet available in the state of Iowa.

Similar to the water constraints, the energy constraints can be formulated as:

$$\sum_r \sum_k \sum_n Y_{rkn} e'_{rkn} + \sum_j e_j^0 X_j \leq E \qquad (9)$$

where e'_{rkn} is per acre of energy in BTU's used by activity r on land class k in PA n, e^0_j is the energy in BTU's used per dollar of output from industry j, and E is the total energy in BTU's available to the state.

Other Constraints

A fixed minimum amount, D_{2n}, of legume and a fixed minimum amount of nonlegume hay production, D_{3n}, are required for livestock consumption in the state. These constraints can be expressed as

$$Q_{2n} \geq D_{2n} \text{ and } Q_{3n} \geq D_{3n} \tag{10}$$

An Application to Ethanol Production

The IO-LP model is used to evaluate the impacts of an ethanol production industry in Iowa. A base and three ethanol runs are conducted. The difference in results between the base and each of the ethanol runs reflects the likely impacts of adding an ethanol industry in Iowa. The year 1975 as the base year is used for estimating the impact. The data used in the IO-LP model are adjusted to reflect price levels of the base year by using the consumer price index, thereby, converting all dollar values to 1975 constant dollars.

The Base Run

The base run is conducted to simulate the outputs from the industry sectors and the crop production in the state of Iowa in the year 1975. Preparation work for running the base run includes estimation of cost coefficients C_{rnk}, crop yield, b_{rmkn}, water use coefficients, w'_{rkn} and

w_j^0, energy use coefficients, e'_{rkn} and e_j^0, input-output technical coefficients, a_{ij}, land RHS values, and final demands of the industries.

The cost coefficients in the objective function, expressed in 1975 dollars, are derived from the Firm Enterprise Data System (FEDS, 1976), U.S. Department of Agriculture, and the Iowa State Cooperative Extension Service Budgets (1975). Crop yields are estimated using 1970 to 1975 average county yields developed by the Iowa Crop and Livestock Reporting Service (1976-1981). The RHS values of land are obtained from the updated 1967 Conservation Needs Inventory (1971). The basic data source for developing the input-output technical coefficients matrix is the 1972 U.S. IO model developed by the Bureau of Economic Analysis (BEA, U.S. Department of Commerce (1979). The procedure to derive the Iowa IO, water usage, energy usage, and employment and income coefficients are in the report (Jones and Huang, 1982). The final demands of the base run are residual estimates obtained from balancing the IO cash flow table the 1972 agricultural production and industry output of the state of Iowa.

The Ethanol Sector

A new ethanol sector is added to the existing 38 industry sectors in the base run. This requires adding new technical coefficients to the IO portion of the model and reestimating the technical coefficients of the existing industry sectors affected by the new ethanol sector. The technical coefficients or the direct inputs from the existing sectors to the ethanol sector and the distribution of the ethanol sector's output, including that sold to each of the 38 industry sectors have to be estimated. The use of ethanol sector's output as substitute inputs to other industry sectors also have to be investigated in order to reestimate the technical coefficients.

Corn is assumed to be the basic feedstock for the new ethanol industry. The wet milling process is assumed for the full ethanol production because it has advantages over the dry milling process (Hertzmark et al., 1980). For each bushel of corn input, this technique yields 2.5 gallons of dry ethanol, 1.7 pounds of corn oil, 11.2 pounds of gluten feed (22 percent protein), and 3.3 pounds of gluten meal (62 percent protein). Other material inputs and energy consumption for the ethanol processes are: 4.38 pounds of coal, 1.26 kw hours of electricity, 0.00018 gallons make-up agent, .24 pounds of lime, and 0.445 pounds of sulfur dioxide for each gallon of ethanol produced (Jack Faucett Associates, 1981).

The purchase and sales patterns of the industrial organic chemicals industry which includes ethanol production, and the distilled liquor industry in the 1972 detailed IO structure of the U.S. economy (Bureau of Economic Analysis, U.S. Department of Commerce, 1979) provided a basis for estimating the industrial flow of goods and services involved in alcohol production. By combining this information with other data acquired from income statements, operating budgets, and technical presentations of ethanol processing/production in other publications the technical coefficients for the ethanol sector are estimated (Butler Research and Engineering, 1979; Emert, Huitink, and Langston, 1980; Shelton, Rider, Retzlaff et al., 1979; Sitton, Foutch et al., 1979). These secondary data sources provided clues as to the flow of inputs and outputs of an ethanol industry in the absence of primary information or firsthand knowledge. The ethanol coefficients used in this application are considered approximations, but were deemed adequate to illustrate the IO-LP application in estimating potential impacts of an ethanol industry in Iowa.

The technical coefficients adding an ethanol sector are shown in Table 1. The figures in the last column of the table are the technical coefficients from the existing sectors to the ethanol sector. These figures are mainly derived from the U.S. IO table. Sectors that provide inputs to the ethanol production are: (1) Corn and other feed grains, (11) Maintenance and repair construction, (19) Printing and publishing, (20) Agricultural chemicals, (21) Chemicals except agriculture, (22) Rubber and miscellaneous plastics, (23) Stone, clay, and glass products, (25) Fabricated metal products, (31) Transportation and warehousing, (32) Communications and utilities, (33) Wholesale and retail trade, (34) Finance, insurance, and real estate, (35) Services, (38) Iowa personal income, and (39) Ethanol.

The ethanol industry output consists mostly of ethanol and stillage or distillers' by-product. It was assumed that the ethanol produced by the industry would be exported out of Iowa and that the stillage by-product would be sold to Iowa farmers and to the feed grains industry in Iowa for use in feed mixtures, replacing some of the requirements for soybean meal. Therefore, only the livestock and poultry, soybean oil mills and grain products industries' input coefficients are adjusted to reflect this product substitution when the ethanol industry was added to the Iowa economy. The intermediate demand for ethanol by the other industry sectors are not considered.

Table 1. Technical coefficients for adding an ethanol sector to Iowa IO-LP model

Sector number[1/]		Meat Industry 4	Poultry and eggs 5	Dairy 6	Other agriculture 7	Grain products 14	Ethanol 39
1	Corn and other feed grains						0.5263[a]
2							
3							
4							
5							
6							
7							
8							
9							
10							
11	Maintenance & repair construction						0.00107
12							
13							
14							
15	Soybean oil meal	.0127053	.0208667	0.0131521	.006928	.0647821	
16							
17							
18							
19	Printing and publishing						0.00042
20	Agriculture chemicals						0.01110
21	Chemical except in agriculture						0.02391
22	Rubber and misc. plastics						0.00061
23	Stone, clay and glass products						0.00170
24							
25	Fabricated metal products						0.00668
26							
27							
28							
29							
30							
31	Transportation and warehousing						0.01830
32	Communications and utilities						0.05204
33	Wholesale and retail trade						0.01703
34	Finance, insurance & stocks						0.04424
35	Service						0.03342
36							
37							
38	Iowa personal income						0.21804
39	Ethanol	0.0020964	0.003443	0.0021701	0.0001143	0.010689	0.03134

[a]This value is obtained by the equation $a_{1,38} = \frac{\text{Price of corn per bushel}}{\text{Value of ethanol + value of ethanol by-product}}$.

Corn price is \$2.9 per bushel. The value of ethanol is \$1.80 gal. x 2.5 gal./bushel which is \$4.50 per bushel of corn. The value of ethanol by-product is mainly from GLM and GLF. About 8 pounds of soybean meal equivalent can be obtained from the by-product which accounts for \$1.01 per bushel of corn processed. Thus, $a_{1,38} = \frac{2.9}{4.5 + 1.01} = 0.5263$.

The sales pattern of industrial organic chemicals industry in the 1972 IO structure of the U.S. economy determines that the meat animals (4), Poultry and eggs (5), Dairy (6), Other agriculture (7), and Grain products (14) sectors are the main users of by-products to substitute soybean meal.

In terms of metabolizable energy and protein content, the feed value of the gluten feed (GLF) and the gluten meal (GLM) produced from one bushel of corn can substitute eight pounds of the soybean meal. This figure of soybean meal equivalent per bushel of corn processed is used to compute total amount of soybean meal equivalent produced from a given level of ethanol export. The ratio of the total amount to the total soybean meal consumed in Iowa during 1975 is considered as the substitution rate. The substitution rate (SR) is used to estimate the new direct input coefficients as follows:

$$a_{39j} = a_{15j} \times SR \qquad j = 4, 5, 6, 7, \text{ and } 14. \qquad (11)$$

The new technical coefficients of soybean mill (15) sector is estimated by the equation:

$$a^{*}_{15j} = a_{15j} - a_{39j} \qquad j = 4, 5, 6, 7, \text{ and } 14. \qquad (12)$$

The figures in row 15 and row 39 of Table 1 are computed for the situation when 130 million gallons of ethanol is exported.

The Ethanol Runs

The runs of the IO-LP model are conduced to examine three export levels of ethanol from the state of Iowa. These export levels are 130, 160, and 520 million gallons. These figures are equivalent to 15, 30, and 60 percent, respectively, of the U.S. annual production targeted by the end of 1982 (Iowa Energy Policy Council, 1981). Each of these export quantities is used to compute the final demand of the ethanol sector in each respective run. Each run assumes that all the ethanol produced is exported out of Iowa, except that consumed by the ethanol sector itself. It also assumes that the by-products GLF and GLM are fully utilized in Iowa as a substitute for soybean meal, while the other by-products such as CO_2 and corn oil are relatively insignificant to the Iowa economy. In each ethanol run, the level of export is converted to the total value of corn for ethanol production. The converted corn value is then used as the required quantities of corn flowing from the feed grains sector (1) to the ethanol sector (39).

Estimated impacts of each export level on the Iowa economy are presented in Tables 2 and 3. Table 2 shows the impact that the ethanol production has on the agricultural production in the state of Iowa, while Table 3 gives the impacts on various industry sectors in the state. An increase in ethanol production, as expected, will greatly increase corn production. Soybean land and hayland provide the main source of land for corn production. The decrease in intermediate soybean demand, because of the substitution by the GLF and the GLM, reduces the need for soybean production. The released soybean land is then brought into corn production.

Table 2. Impact of ethanol production on Iowa's agriculture

	1975 Actual	Base run	Deviation from the base run annual ethanol export level: 130 Million gallons	260 Million gallons	520 million gallons
	1000 bushels				
Corn	1,070,000	1,040,667	+57,106	+114,219	+231,704
Soybeans	236,980	239,608	-4,286	-8,589	-17,293
Oats	79,500	77,623	-2	-3	-6,512
Wheat	3,400	981	+1	+3	+5
Sorghum	1,612	7,841	0	+1	+1
Silage	NA	11,070	0	0	0
Legume and nonlegume hay	NA	20,644	-1,506	-3,035	-5,801
	Acres harvested				
	1000 acres				
Corn	12,130	10,743	+539	+1,064	+2,235
Soybeans	6,970	6,894	-140	-261	-464
Oats	1,540	1,546	0	0	-120
Wheat	75	25	+1	+1	+1
Sorghum	26	161	0	0	0
Legume and nonlegume hay	NA	6,667	-398	-801	-1,642
Gross soil loss (1000 tons)	NA	117,948	-1,267	-1,463	+15,594
	1000 dollars				
Net crop income		3,496,740	59,300	117,402	232,755

Table 3. Impact of ethanol production to total gross output of Iowa's industry sectors

Sector number and title	Deviation from the base run Annual ethanol export levels in $1000		
	130 mil. gal.	260 mil. gal.	520 mil. gal.
1. Corn and other feed grains	163,846	327,688	655,360
2. Soybeans	-25,584	-51,305	-103,122
3. Wheat and other food grains	3	5	11
4. Meat animals	14,897	29,785	59,537
5. Poultry and eggs	531	1,061	2,120
6. Dairy farm products	2,749	5,496	10,988
7. Other agriculture	1,125	2,250	4,497
8. Agricultural services	1,677	3,354	6,701
9. Mining	3,167	6,333	12,662
10. New construction	0	0	0
11. Maintenance and repair construction	9,982	19,958	39,894
12. Meat and poultry products	8,780	17,554	35,082
13. Dairy products	4,322	8,641	17,271
14. Grain products	3,102	6,202	12,397
15. Soybean oil mills	-29,308	-58,771	-118,127
16. All other food and kindred products	6,736	13,468	26,921
17. Textile mill and apparel	3,116	6,229	12,452
18. Lumber and wood products	5,293	10,582	21,151
19. Printing and publishing	3,787	7,573	15,138
20. Agricultural chemicals	10,401	20,800	41,587
21. Chemicals except agriculture	14,239	28,474	56,933
22. Rubber and miscellaneous plastics	4,661	9,319	18,626
23. Stone, clay, and glass products	2,179	4,356	8,709
24. Primary metal products	1,935	3,868	7,731
25. Fabricated metal products	4,615	9,227	18,444
26. Farm machinery and equipment	1,590	3,178	6,351
27. Machinery, except electrical and farm	2,628	5,253	10,499
28. Electric and electronic equipment	5,172	10,342	20,672
29. Transportation equipment	10,738	21,470	42,916
30. Other manufacturing	4,196	8,389	16,770
31. Transportation and warehousing	20,281	40,547	81,038
32. Communications and utilities	39,935	79,855	159,655
33. Wholesale and retail trade	59,058	118,082	236,034
34. Finance, insurance, and real estate	97,106	194,153	388,089
35. Services	83,236	166,426	332,676
36. Federal Government enterprise	1,858	3,715	7,426
37. State and local government enterprises	544	1,088	2,176
38. Iowa personal income	308,271	616,352	1,231,993
39. Ethanol	294,775	589,549	1,179,099
Total	1,145,639	2,290,546	4,578,357

The additional land needed to meet the ethanol production level then comes from the hayland. At the 520 M.G. level of ethanol production, some oats land is brought into corn production

Levels of ethanol production have different impacts on soil loss. At the 130 and 260 M.G. production level, a reduction in soil loss is noted, while at the 520 M.G. production level, an increase in soil loss is obtained. At the lower level of production, the additional corn production comes from a shift of soybean-corn rotation to continuous corn and from a conversion of hayland into corn production. The gain in reducing soil loss from the shift of soybean to corn is greater than an increase of soil loss from the conversion of hayland to corn production. As the ethanol production reaches the 520 M.G. level, additional land for corn production comes from low erosive soybean land and high erosive hayland. This results in a net increase in soil loss.

The impact on the state's economy is profound. The value of the state's total gross output[1/] increases 1,145, 2,290 and 4,578 million dollars and Iowa personal income (38) increases 294, 589 and 1,179 million dollars for the three levels of ethanol exports. Individual industries that enjoy a significant increase in total gross output are corn and other feed grains, finance, services, trade, communications and utilities, and transportation and warehousing. Individual industries that suffer a decrease in total gross output are the soybean and soybean oil mills sectors.

Conclusions

An Iowa IO-LP model has been developed to quantify the impacts of fuel ethanol production on agricultural production and various industrial sectors in the state of Iowa. Using the three ethanol export levels of 130, 160, and 520 million gallons per year, indicates that an IO-LP model can provide estimates of the magnitude of production shifts from hay, soybeans, and oats to corn and changes in the total gross output in each of the other 38 industry sectors in Iowa at various production levels. Other useful information, such as effects on water, energy and employment can also be derived by using the outputs of the model.

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