Future Crop Prices and Quantities: Influence of Alternative Crop Yields[1]

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Many people have tried to analyze what the future holds for continued increases in crop yields. After studying time series of average U.S. yields for 19 crops, Lin and Seaver [6] concluded that 12 crops including corn, cotton, and wheat have reached a yield plateau, and the seven remaining crops including hay and soybeans yields have had a slowdown in their rate of growth. On the other hand, after presenting some of the possible new technologies or changes in existing technologies that could boast yields, Wittwer [15] concluded that it is reasonable to expect possible large increases in yields. Wittwer's list of possible technologies included: changes in the plants' ability to withstand environmental stress; changes in the plants' ability to utilize fertilizer including the possibility of more plants with nitrogen fixation capabilities; increases in the plants' photosynthetic efficiency; and increases in the use of chemical growth regulators. Heady [5], after reviewing a host of other studies, observed that probably the best that can be hoped for in the future is the continuation of the current absolute increases in yields.

Pope [7, pp. 107-108] concluded after studying the time series of crop yields for five crops in five Corn Belt states:

> Projections of yields such as have been made for the five Corn Belt states in this study, can only be viewed with a great deal of caution because these projections depend on so many things, some of which we can control, some of which we can't. However, these projections do illustrate that, even in the Corn Belt where great increases in yields have already been experienced, there is little evidence in the past trends to project a general leveling off of crop yields. What will happen to Corn Belt yields in the next twenty years depends on the motivation and ability of American

> agriculturists, the dedication and support of the American public, and the economic, social, and political conditions that prevail.

As Pope concludes, the future of crop yields is dependent upon a host of factors, many of them unknown at the present time.

What is known, however, is that future crop yields will play an important role in determining future crop production, cropland needs, and the ability of the United States to continue to export large amounts of wheat, feed grains, and soybeans. The level of future U.S. crop production needed in the future is highly dependent on both domestic and foreign demands. Demand here and abroad is dependent upon prices and the level of livestock production. Perhaps the real concern should not be future crop yields or production but rather the price of the quantity that is available.

The objective of this study is to determine the year 2000 price-quantity relationships for alternative crop yields. The price quantity relationships for six crops-barley, corn grain, oats, sorghum grain, soybeans, and wheat-are considered in the analysis. In addition supply for silage, hay, and cotton are considered.

Methodology

The method chosen to determine the future price-quantity relationship is an application of the tatonnement model developed at the Center for Agricultural and Rural Development (CARD) [8]. The CARD tatonnement model is an iterative technique used to solve a spatial linear programming model and an econometric model for approximate equilibrium prices and quantities. The demand for the commodities is determined by an econometric model using the shadow prices obtained from the linear programming model. Basically the model works as follows:

a. A starting quantity of demand is determined for each commodity
b. A spatial linear programming model is used to determine at what price producers would supply those quantities at the point of demand
c. That price is used in demand equations for food, feeds, and net exports of each commodity to determine the quantity demanded.
d. The quantity demanded and supplied are compared.
e. If the excess demand is sufficiently small, the price-quantity relationship has been found.
f. If it is large a new quantity to be supplied is determined and the sequence restarted.

Details of the modeling technique can be found in Schatzer, English, and Heady [9] or Schatzer and Heady [10]. For a discussion of the uniqueness, stability, and convergence of tatonnement procedures see Ginsburgh and Waelbroeck [3].

The demand equations for the model are estimated on a national basis. The quantity demanded is disaggregated into food, feed, and export components. Soybeans has no food component. The demand for soybean oil is considered to be insignificant in determining the soybean equilibrium market.

A total of 17 equations are estimated -- six feed, six net export, and five food demand -- using data for the years 1950 to 1979. The equations are estimated using seemingly unrelated regression. The net export equations are estimated as functions of own price, government exports of the commodities, competing crop prices, time and some dummy variables representing changes in government crop program policies. The feed equations are estimated as functions of own price, quantities of production of various livestock commodities, competing crop prices, and the dummy variables representing changes in government crop program policies. The food equations are estimated as functions of own price, competing crop prices, population, and price indices of other food and nonfood items. The estimated equations can be found in Schatzer [8] or Schatzer and Heady [10].

An interregional linear programming model is used to simulate the supply side of the tatonnement model. The linear programming model is constructed for the year 2000 and is based upon models previously developed at the Center for Agricultural and Rural Development [12, 2].

The linear programming model is a regionalized, one land group specification covering the geographical area of the continental United States. The 48 states are divided into 105 producing areas (PAs). PAs 48 to 105 serve as water supply regions and are the only PAs where irrigation is allowed. The PAs are aggregated into 28 market regions (MRs) which serve as the smallest breakdown for commodity demands and transportation activities.

The objective function of the linear programming model minimizes the total cost of crop production and transportation. The costs include labor, machinery, pesticides, fertilizers, water, energy, and transportation from the location of the production centers to the location of the consumption centers.

Restraints in the model are defined for land, water, and commodity demands. The driving force in the linear programming model is the restraints on the minimum levels of the commodity demands at the market region level as determined by the demand equations. The land and water restraints are defined at the PA level. The cropland available in each area is adjusted for exogenous crop requirements and nonagricultural uses. The amount of land available is based on the 1977 National Resource Inventory [14]. There are two water restraints for each of the water supply PAs (PAs 48-105), one for groundwater and one for surface water. These restraints balance the dependable water supply in the region for interbasin transfer, natural flow and runoff, and water use. Water consumed on site by livestock and exogenous crops, by municipal and industrial uses, and water exports is predetermined and is subtracted from the available water supply.

Three classes of activities are defined in the linear programming model: crop production, commodity transportation, and resource supply. Crop production activities are defined to simulate the rotations in use by PA for barley, corn grain, corn silage, cotton, legume hay, nonlegume hay, oats, sorghum grain, sorghum silage, soybeans, and wheat. The rotations contain one to four crops and cover from one to five years. Each rotation may be produced by three tillage methods; conventional tillage with residue removed, conventional tillage with residue left, or reduced tillage.

The costs for the rotations are derived from the Federal Enterprise Data System [13]. The rotation costs represent the per acre non-land-variable cost, excluding nitrogen costs. These costs are adjusted to reflect the given conservation-tillage practice that the rotation represents. The adjustment is primarily based on timing factors that indicate the time variance for each practice.

Commodity transportation activities define the shipment of a commodity from one market region to another -- one activity for shipment in each direction. Transportation activities are defined for barley, corn grain, oats, sorghum grain, soybeans, and wheat. All transportation is assumed to be done by railroads since the majority of long hauls are by railroads.

Resource supply activities are defined for water, nitrogen, and land conversion. Water activities allow for the movement of the water from the water supply rows to the water demand row. Other water activities allow for movement of water from one region to another through down-stream flows or interbasin canal flows. Nitrogen activities allow for the purchase of commercially produced nitrogen once a specific amount of nitrogen derive from livestock wastes is exhausted. Land conversion activities allow for the conversion of pasture and forest land to cropland. These activities are defined based on the high potential land available for conversion as defined in the 1977 NRI [14]. Approximately 36 million acres has been classified as having a high potential for conversion to cropland. If land is converted, a cost is incurred which increases the cost of production. The cost of conversion and the distribution to the producing areas was provided by Gray [4].

The demands for four crops not represented by the demand side of the model are determined exogenously. These crops are silage, cotton, legume hay, and nonlegume hay. Cotton demand is on a national basis, while silage and hay demands are on a regional basis. Silage and hay demands are distributed to market regions based on livestock feed demands [1]. National cotton demand is set at 17.8 million bales with 108.9, 82.2, an 65.5 million tons assumed for sillage, legume hay and nonlegume hay; respectively. Nonlegume hay demand can be increased as a result of irrigating crops with water exogenously allocated to pasture. If the water is not used on the pasture, nonlegume hay production is increased to make up the loss of feed value.

The estimated demand equations determine the quantity demanded on a national basis and the linear programming model is driven by market region demands. Linear programming activities are developed which distribute the national demands to the market regions. By crop, these activities distribute net exports based on port weights, food demand based on population weights, and feed demand based on livestock feed weights. The linear programming model then provides national average shadow prices for each crop by food, feed, and net export demand. The demand equations need a single national overall average price for each crop so a weighted average price is determined using the demands as weights for each crop.

Description of Alternatives

Three yield levels are analyzed. These levels provide a range of potential crop yields for the year 2000. The three yield levels are developed using functions based on those estimated by Stoecker [11] and modified as documented in English, Alt, and Heady [2]. A unique yield is determined for each crop in the activity as a function of the producing area, crop rotation, tillage method, optimal fertilization rate, irrigation versus dryland, and time trends.

The three yield levels used in this study are determined by using three different time trend values. For the medium yield alternative (MEDYLD), the time trend value for the year 2000 is used. The time trend value is increased by 15 for the high yield alternative (HIGYLD) and decreased by 15 for the low yield alternative (LOWYLD). While yields do vary by rotation due to nitrogen carryover and producing area, the range of potential yield can be seen by looking at the dryland continuous crop yields for one producing area (PA). Table 1 gives these yields for one PA. The rate of yield changes varies by crop between alternatives. In addition the relative yields between PAs for a crop may change for each alternative. The final national average yield for each crop is a function of how the crop is grown, where it is grown, and how much of it is grown.

The demand equations contained several exogenous variables that require a value for the year 2000. These values are obtained by forecasting or using averages of historical data. The value used for several of the important variables along with the 1979 value is presented in Table 2.

Results

The three alternative yield levels are simulated using the tatonnement model which provides the optimum price-quantity relationships for each yield level. The model provides regional

Table 1. Continuous crop yields for each alternative for one of the producing areas.

	Yields[a]			Fraction of LOWYLD	
Crop	LOWYLD	MEDYLD	HIGYLD	MEDYLD	HIGLYD
Barley	49.50	57.60	67.70	1.164	1.327
Corn	102.95	119.64	136.33	1.162	1.324
Oats	63.02	75.29	87.55	1.195	1.389
Sorghum	70.34	80.11	89.89	1.139	1.278
Soybeans	36.77	42.74	48.71	1.162	1.325
Wheat	40.89	45.62	50.44	1.116	1.234
Cotton	1.26	1.49	1.70	1.178	1.345
Legume Hay	3.09	3.29	3.50	1.065	1.133
Nonlegume Hay	2.10	2.34	2.59	1.114	1.233
Corn Silage	12.51	13.19	13.87	1.054	1.109
Sorghum Silage	13.58	14.16	14.49	1.043	1.067

[a]Yields are in bushels/acre except cotton which is in bales/acre and hays and silages which is in tons/acre.

Table 2. Projected value for 2000 and the 1979 actual value for the exogenous variables in the demand equations.

Variables	Units	1979 value	2000 value
Beef production, live weight	billion pounds	38.937	58.219
Chicken production, ready-to-cook weight	billion pounds	11.920	16.496
CPI[a] for fruits and vegetables[b]	1975 = 1.00	0.997	1.075
CPI less food[b]	1975 = 1.00	1.005	1.015
CPI for meat[b]	1975 = 1.00	0.996	0.883
Egg production	billion dozen	5.769	5.844
Lamb production, live weight	billion pounds	0.712	0.725
Personal disposable income[b]	$1000/capita	5.535	7.505
Pork production, live weight	billion pounds	22.617	20.883

[a]CPI is the Consumer Price Index.

[b]These variables are deflated by the Consumer Price Index for all items.

results that are too numerous to analyze in this paper. Therefore, only national results for each alternative are presented.

Yields

As explained previously, the national average yield for each crop is a function of the activities entering the solution. These yields are presented in Table 3 for dryland, irrigated land and all land. The average yield on all land increases as the activity yield levels increase for each of the crops except oats which declines. Oat yields decline as a result of two things -- more oats being produced and the increase in the amount of oats produced in the Great Plains. Another occurrance that might be questioned, is average dryland corn yields are higher than average irrigated corn yields in the high yield solution. Much less land is needed to produce corn in HIGYLD, so much of the dryland production occurs in the highly productive PAs of the Corn Belt.

While the oat yield and corn yield results may seem questionable, they occur as a result of the quantity produced, where it is produced, and the type of rotation used to produce it. Yields for each crop for a given activity in a PA increase from LOWYLD to MEDYLD to HIGYLD and irrigated yields for a given PA are higher than dryland yields. The two results may add some insight to some of the concern about yields reaching a plateau. The suggestion of yield plateaus may be the result of mistaken analysis. Acres of land in production have changed substantially during the past twenty years along with the relative importance of certain areas to certain crops. The yield potential of the best soils may be increasing at the same rate but be masked in national and regional statistics by

Table 3. National average yields[a] for each crop for all land, dryland and irrigated land for the three yield alternatives.

	Dryland Yields			Irrigated Yields			Overall Yields		
Crop	LOWYLD	MEDYLD	HIGYLD	LOWYLD	MEDYLD	HIGYLD	LOWYLD	MEDYLD	HIGYLD
Barley	41.26	53.57	63.41	70.44	74.33	74.41	43.59	54.61	63.81
Corn	101.33	108.85	121.78	111.95	113.34	117.15	102.81	109.05	121.64
Oats	87.05	65.70	59.34	87.82	80.11	82.97	87.08	66.23	59.49
Sorghum	50.27	57.29	66.28	88.45	91.44	91.39	59.60	60.06	67.44
Soybeans	27.62	34.60	40.02	41.62	47.88	54.35	27.62	34.70	40.10
Wheat	31.92	35.12	39.50	55.95	60.32	69.56	34.16	35.67	40.17
Cotton	1.09	1.14	1.33	1.76	2.07	2.12	1.12	1.17	1.35
Hay	2.18	2.55	2.89	3.68	4.03	4.38	2.42	2.77	3.08
Silage	12.51	13.43	14.18	18.49	18.26	18.74	13.71	14.34	15.00

[a]Yields are bushels/acre except cotton which is in bales/acre and hay and silage which is in tons/acre.

increased cultivation of less productive soils and movements in areas of production.

Price-Quantity Relationships

The prices and quantities for each crop are shown in Table 4. The prices for barley, corn, oats, sorghum, soybeans, and wheat are average market clearing prices. These are national average prices that the producers require to supply and the consumers require to demand the quantities shown. The prices for cotton, hay, and silage are the average national supply pries required by producers to produce the exogenously specified demand quantities. The percent of each crop produced with irrigation is also presented in Table 4.

As activity level yields increase, general prices decline and quantities increase. Cotton and silage quantities are fixed exogenously, so they are constant. Hay quantity is also fixed exogenously except that irrigation water which is exogenously allocated for pasture can be used endogenously on other crops, decreasing pasture production and increasing the quantity of nonlegume hay required. As activity level yields increase, less area is irrigated and the required hay production decreases. The other exception in prices declining and quantities increasing is barley quantity. Barley quantity is largest with medium yields. In the high yield alternative, due to the relative prices, demand for barley for exports and feed declines as compared to the medium yield levels.

The relative range in magnitudes of prices across alternatives is much wider than the relative range in quantities. The wider price range is expected since agricultural commodities usually have

Table 4. Crop prices, quantities and percent of production irrigated for three yield alternatives.

Crop	Prices[a]			Quantities[b]			Percent of production irrigated		
	LOWYLD	MEDYLD	HIGYLD	LOWLYD	MEDYLD	HIGYLD	LOWYLD	MEDYLD	HIGYLD
Barley	4.09	1.85	1.45	592.61	616.59	596.21	12.88	6.80	4.22
Corn	3.83	1.95	1.48	9,013.98	9,197.71	9,231.76	15.24	4.67	2.88
Oats	2.87	1.53	1.17	216.79	432.34	510.31	3.58	4.45	.91
Sorghum	4.56	2.27	1.72	1,364.94	1,405.84	1,425.21	36.26	12.33	6.23
Soybeans	9.70	4.37	3.14	2,980.29	3,147.07	3,177.17	.08	1.10	.80
Wheat	6.10	2.88	2.16	1,662.78	1,882.10	1,923.50	15.25	3.67	3.88
Cotton	298.42	200.57	178.22	17.75	17.75	17.75	6.82	6.37	5.07
Hay	112.89	51.39	39.61	155.52	154.53	153.30	24.34	21.19	17.87
Silage	27.09	15.36	12.39	108.90	108.90	108.90	27.17	24.09	22.47

[a]Prices are $/bushel except cotton which is in $/bale and hay and silage which is in $/ton and are in 1975 dollars.

[b]Quantities are million bushels except cotton which is in million bales and hay and silage which is in million tons.

inelastic demands. Quantities also cannot vary completely since livestock production is fixed and feed demands are largely determined by livestock production. Feed demand is therefore highly inelastic in the model. If livestock production had been a function of feed prices the price ranges would have been smaller and the quantity ranges larger.

The relative change in prices are generally larger than the relative changes in average national yields while quantity changes are smaller. Corn yield in MEDYLD increases about 6 percent compared to those in LOWYLD while corn price declines about 49 percent and corn quantity increases approximately 2 percent. With HIGYLD compared to MEDYLD, corn yield increases 11.5 percent, corn price declines about 24 percent and quantity increased less than 1 percent. The changes in quantity and prices are less in most cases when HIGYLD is compared to MEDYLD than when MEDYLD is compared to LOWYLD.

Acres

Since quantity generally increases less than yield, acres used to produce the crop decline as activity level yields increase. Acres used to produced each crop for each alternative are presented in Table 5. Total acreage in all crops, including acres in summer fallow, is 388.89 million acres in LOWYLD, 379.90 million acres in MEDYLD and 344.04 million acres in HIGYLD. The reason for the small decline between LOWYLD and MEDYLD is the large increase in summer fallow acres. The LOWYLD solution uses all of the land available and has only 17.61 million acres of land in summer fallow.

Table 5. Acres used to produce each crop and percent of the acres irrigated for the three yield alternatives.

	Acres[a]			Percent of acres irrigated		
Crop	LOWYLD	MEDYLD	HIGYLD	LOWYLD	MEDYLD	HIGYLD
Barley	13.60	11.29	9.34	8.01	4.96	3.53
Corn	87.67	84.34	75.89	13.98	4.48	2.99
Oats	2.49	6.53	8.58	3.61	3.68	0.70
Sorghum	22.90	23.41	21.13	24.41	8.12	4.59
Soybeans	107.90	90.69	79.22	0.06	0.79	0.58
Wheat	48.68	52.76	47.88	9.31	2.16	2.23
Cotton	15.87	15.18	13.13	4.35	3.62	3.20
Hay	64.23	55.81	49.78	16.00	14.55	12.58
Silage	7.94	7.59	7.26	20.15	18.84	18.04
Fallow	17.61	32.29	31.83	0.00	0.00	0.00
TOTAL	388.89	379.90	344.04	9.31	4.64	3.83

[a]Acres is in millions.

The land constraint contributed to the higher prices in the LOWYLD solution since the endogenously determined land rental value increases rapidly when land becomes scarce. Land scarcity is also indicated by the percent of land irrigated, also shown in Table 5. About 9.3 percent of the acres are irrigated in the low yield alternative compared with only 4.64 and 3.83 percent for the medium and high yield alternatives, respectively. The endogenously determined land rental rates, averaged $169.16/acre for the low yield alternative compared to only $47.53/acre and $26.52/acre for the medium and high yield alternatives, respectively.

Conclusions

The results add some insights into the concern over whether the current growth rate in yields is slowing down and yields are reaching a plateau. The results show that even with high activity level yields (HIGYLD), national average yields may be less than national average yields with lower activity level yields (LOWYLD). Where and how much of the crop is produce is important in determining national or even regional average yields. Acres of land in production have changed over time as more of certain crops are produced.

The results also suggest low yields in the future may put a strain on the crop land base. The strain however translates to good and bad news for farmers as prices of crop output rise but the potential rental value of land also increases. This strain would cause the conversion of some of the current rural lands which are in pasture, range, or forest to cultivated crop uses.

Finally, the projections of crop price-quantity relationships made in this study must be viewed with caution. The results must be analyzed with the basis assumptions and structure of the model kept in mind. Many things which can influence future crop demands may not be captured in the demand equations used. Also many things which can influence future crop supply may not be captured on the supply side.

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