ALLOCATION OF AGRICULTURAL PRODUCTION CAPACITY AMONG COMMERCIAL MARKETS, FOOD AID, AND PRODUCTION CONTROL*

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Intermittent periods of excess supply as well as excess demand are likely to characterize American agriculture in the years ahead. Government again may choose to intervene to clear the market at acceptable prices during periods of excess supply. The principal means of removing excess capacity has been to restrain output through voluntary programs which pay farmers to divert cropland to soil-conserving uses and through aid programs which dispose of surpluses in needy countries, presumably in ways that do not interfere with commercial exports. But have these programs provided (a) maximum net farm income, (b) maximum real foreign aid, or (c) minimum U.S. Treasury Cost?

This study reports a model to estimate the most efficient allocation of agricultural capacity with a domestic general land retirement program and food aid to foreign nations. The paper is of historic interest in showing efficient use of resources, given the past intervention of government in markets, and of methodological interest for improving decisions, should government again elect to dispose of excess production capacity through domestic acreage controls and food aid to foreign nations.

ANALYTICAL FRAMEWORK

Economic efficiency can be achieved by optimally allocating agricultural capacity (a) among geographic regions through acreage diversion, (b) among foreign countries receiving food aid, and (c) between domestic acreage diversion and food aid given optimality in (a) and (b). One possible way to achieve optimality between acreage diversion and food aid is to minimize treasury cost subject to a specified level of real aid and net farm income. If the program operates efficiently, these results would be the same as maximizing net farm income or real aid subject to the appropriate restraints.

Efficient food aid allocation allows recipient countries to attain maximum benefit for economic progress from a given value of such assistance. In order to achieve maximum efficiency, this aid must be distributed according to the marginal value that each country receives from the additional goods. The marginal value of food aid refers to the amount of untied cash assistance estimated to yield the same benefit for economic progress as an additional small increment in the value of food donations. The marginal value curve of all countries is the horizontal summation of the marginal value curves of the individual countries.

This study is concerned only with the aid allocation among countries and takes the total level of real aid to all countries as given.[1] Later the restraint is presented that real aid be maintained at a specified level, but only as applied to total aid to all recipients, not to each individual country. Thus, through an efficient allocation, real aid is likely to differ from actual aid for any one country. By holding the total level of real aid constant, the condition of recipient nations in *aggregate* remains unchanged, but the reallocation process does make some countries worse off while others are made better off.

Economic efficiency in production diversion

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[1] Real aid is defined as the summation of the value of nonfood aid and the respondents' perceived value of food aid in economic progress.

programs can be measured by the treasury cost to remove each dollar of output; the most efficient program first would remove cropland with the lowest net return per unit of production. Two types of voluntary land withdrawal programs based on this economic efficiency criterion are considered.

Under the perfectly discriminating program, production is withdrawn at a cost equal to the net returns on each unit of production diverted plus the cost of conservation practices in lieu of producing that unit. A payment equal to the net returns on each unit is the minimum payment that a profit-making farmer would accept not to produce that unit.

A more easily administered program would provide equal payments for each unit of production diverted. The payments per unit under this type of program would be equal to the net returns per unit of production on the last unit diverted. Basing the payments on the marginal unit insures the minimum treasury cost for the desired level of diversion, given that each farmer is paid the same amount per dollar of production diverted.

DATA SOURCES

Marginal value of food aid was estimated by using a mail survey of the major food aid recipient countries.[2] Individuals with a considerable knowledge of economic development and external economic assistance programs and needs estimated the amount of untied cash assistance that would yield the same benefit for economic progress as specified additional increments in the value of food donations.[3] The value of food aid to recipient countries was estimated for a $1 million increase and a 25 percent increase in the 1964-1966 level of food aid.

Zepp and Sharples [8] estimated supply functions of retired cropland for the United States and also for each major agricultural region. They estimated the planted acreage and production of 15 major crops under no production control programs, and then divided this total cropland into 568 components. Average net returns over variable costs per acre received by farmers for each of the 568 crop components were then computed, with no charge made for land costs, operator and family labor, or machinery depreciation. The land to be retired was obtained by arraying the 568 crop components by the treasury cost of retiring a dollar of output, lowest to highest, and accumulating acres.

Five additional restrictions were considered in deriving the supply functions for retired land. First, no retired acre could receive less than $3 an acre retirement payment. Second, each retired acre received an additional $2 to cover costs of conservation practices. Third, a maximum of 30 percent of the total cropland in any one production area could be retired. Fourth, no more than 50 percent of the planted acres of any crop in any production area could be retired. Fifth, factors affecting irrigated crops were assumed to preclude their participation in a general cropland retirement program. The model includes geographic price differences for each commodity.

THE MODEL

The following model provides a mathematical framework to minimize the treasury cost of production control and foreign aid, subject to a given net farm income and a given level of real foreign aid. The quantities that the government must divert or export under aid to maintain net farm income are assumed to be jointly determined with current market prices and output. In the intermediate run – the 3-year period for which this model was designed – the cost to the government of land retirement and food aid is a function of the current market price.

The government has three instrumental policy variables which it can manipulate to achieve its objectives in net farm income and real aid: food aid, nonfood aid, and diverted production. To minimize treasury cost subject to specified levels of net farm income and real aid, the following formulation is applicable.

The Variables

Notation included in the model is as follows:

Variables:

AV	=	average real value per unit of food aid to recipient countries,
C	=	cost,
E	=	operating expenses,
f	=	functional relationship,
g	=	government cost per unit as a percentage of farm price,
k	=	specified constant,
NFI	=	net farm income,
P	=	price,
PC	=	production capacity,
Q	=	quantity,

[2]The survey countries received 70 percent of the total U.S. food aid during 1964-1966.

[3]Estimation procedures and actual estimates of the marginal value of food aid by survey country are found in Pinstrup-Andersen and Tweeten [4].

RA	=	real aid,
t	=	transportation cost per unit as a percentage of farm price, and
TC	=	total treasury cost.

Subscripts:

D	=	diverted,
F	=	farm,
FA	=	food aid,
FP	=	farm program,
M	=	marketed, and
NFA	=	nonfood aid.

Analytical Model

Minimize: (1) $TC = C_{FP} + C_{FA} + C_{NFA}$

Subject to: (2) $RA = AV_{FA} \cdot g \cdot P_F \cdot Q_{FA} + C_{NFA} \geqslant k_1$

(3) $NFI = P_F \cdot (Q_{FA} + Q_M) - E_F + C_{FP} \geqslant k_2$.

These three equations can be calculated from the basic relationships given below.

(4) $Q_M = PC - Q_D - Q_{FA}$,

(5) $P_F = f_1\ (Q_M)$,

(6) $E_F = f_2\ (Q_M + Q_{FA})$,

(7) $C_{FP} = f_3\ (Q_D, Q_{FA})$,

(8) $C_{FA} = g \cdot (1+t) \cdot P_F \cdot Q_{FA}$, and

(9) $AV_{FA} = f_4\ (g \cdot P_F \cdot Q_{FA})$.

By making the appropriate substitutions in equations (1) through (9), the system can be reduced to three equations explaining treasury cost, real foreign aid, and net farm income.

Empirical Model[4]

Empirical estimates of all variables and functional relationships for the above model are presented in this section. The equations listed below are numbered to correspond to their counterpart in the conceptual model, and together with identities complete the nine-equation model.

Real aid and net farm income were assumed to be held constant at their average 1964-1966 values. The real aid component of food aid (k_1) was \$495.6 million [3]. Average net farm income (k_2) was \$16,729.1 million [7].

Value of potential net farm output, which included actual production minus intermediate sales plus potential production of land withdrawn under government farm programs, averaged \$39,577 million fo. he 1964-1966 period. This value of potential net farm output, divided by the index of prices received by farmers (1964-1966 = 100 percent), gave a production capacity (PC) of 39,577. Average value of production marketed through regular commercial channels was \$36,002 million. The farm price equation was formulated using this value of production marketed and assuming the price elasticity of demand for farm output to be -.33 for this intermediate-run period.

Annual farm operating expenses for the period averaged \$21,913 million. As production was extended to marginal land, variable operating expenses per dollar of output increased dramatically. Assuming constant 1964-1966 farm prices, the equation for farm operating expenses used in the model was:

(6) $E_F = 6200.2623 + .4274\,(Q_M + Q_{FA})$.

Since prices received by farmers depended on production marketed, the cost per unit to the government of a voluntary production-diversion program based on net receipts varied directly with production diverted either through land withdrawals or government-financed export programs. The treasury cost of diverting production also increased rapidly as production was diverted on more profitable farms. The total treasury cost of removing production was estimated by regressing treasury cost of removing production on three variables: quantity diverted, the square of quantity diverted, and quantity of food aid; the average and marginal cost curves can be derived from this equation. The average cost curve of paying farmers for dierted production according to the marginal unit was equivalent to the marginal cost curve derived above. When payments for diversion were based on (1) each unit diverted and (2) the marginal unit diverted, the total cost curves were, respectively:

(7a) $C_{FP} = -233.59 + .2215\,Q_D + .0001023\,(Q_D^2) + .00008332\,(Q_{FA} \cdot Q_D)$ and

(7b) $C_{FP} = .2215\,Q_D + .0002047\,(Q_D^2) + .00008332\,(Q_{FA} \cdot Q_D)$.

Food aid was valued at export prices, which was assumed to cover purchases at the farm level plus

[4] The statistical properties of the following equations have not been given because some give perfect fits by assumption and all others have R^2's, greater than .98 with all coefficients highly significant.

storage, transportation, and handling enroute to Gulf Port. A weighted average of export prices for the 1964-1966 period was approximately 25 percent above prices received by farmers; thus, g (government cost per unit) was 125 percent of farm price. The United States' share of transportation charges to recipient countries (t) only amounted to 1.7 percent of export value.

The relative value to recipients of food aid at the margin was the marginal rate of substitution of food for untied cash assistance. The summation of the marginal value equations gave the aggregate marginal value, which then was used in the derivation of the aggregate average value equation. Using the same proportional distribution between grants and long-term loans as actually occurred in the 1964-1966 period, the equation showing the average real value per unit of food aid was:

$$(9)\quad AV_{FA} = .5730 - .00005403\,(g \cdot P_F \cdot Q_{FA}).$$

At least two programs can be evaluated by incorporating these estimates into the theoretical model. The model of a discriminatory payments program, paying farmers only the minimum amount required to divert each acre, was made up of equations 1-6, 7a, 8, and 9. The model of the uniform payments program, paying each farmer the same ratio of payment to value of production per acre as required on the last acre diverted, was derived from the above model by substituting equation 7b for equation 7a.

OPTIMIZING PROCEDURE

The model is formulated using Lagrange multipliers and the three equations explaining treasury cost, real foreign aid, and net farm income. The Lagrangian expression to be minimized is a function of the three policy variables (production diversion, food aid, and nonfood aid) and λ_1 (associated with the constraint on real foreign aid) and λ_2 (associated with the constraint on net farm income). Minimizing the Lagrangian expression below is equivalent to minimizing treasury cost subject to the desired levels of real foreign aid and net farm income.

$$TC = C_{FP} + C_{FA} + C_{NFA} + \lambda_1\,(f(C_{FA}, C_{NFA}) - k_1) + \lambda_2\,(f(C_{FP}, C_{FA}) - k_2)$$

Because both the objective function and the constraints contain nonlinearities, the Newton method is used to solve this nonlinear programming problem.[5] The first- and second-order derivatives of the Lagrangian expression with respect to each of the five variables are used in solving the system. The optimal solution is computed iteratively from initial estimates.

RESULTS

The optimal combination of production control, food aid, and nonfood aid which minimizes treasury cost while maintaining existing levels of net farm income and real aid was determined for both the discriminatory and uniform payments program for the 1964-1966 period (Table 1).

Discriminatory Payment Diversion Program

The discriminatory payments program called for an increase in production diversion and a decrease in food aid from actual 1964-1966 levels, which would have markedly reduced treasury costs. Leaving the actual value of food aid unchanged, the optimal value of diverted production was 6 percent below its actual value, and treasury cost was 34 percent below the 1964-1966 treasury cost. Alternatively, with the given values of diverted production, net farm income, and real aid, then treasury costs were reduced 36 percent by optimally allocating food aid.

Treasury cost could be reduced further by allowing both the value of diverted production and food aid to vary from their 1964-1966 levels. In order to maintain existing levels of net farm income and real aid, the minimum treasury cost under the discriminatory payments program was $2,457 million, or 41 percent below the actual outlay. The optimal value of diverted production was $3,296 million which was 21 percent more than the actual value diverted. The government farm payments necessary to divert this much production amounted to $1,695 million. The optimal value of food aid, $565 million, was only 38 percent of the 1964-1966 actual value; this amount of food aid would cost the U.S. government $573 million, which included its share of ocean transportation. With such a low level of food aid, direct grants of $189 million were required to maintain real aid.

The Lagrange multipliers at the optimal values of the policy variables indicate the marginal cost to the government of increasing real aid and net farm income. The marginal cost of increasing real aid by $1 was $1, and the marginal cost of increasing net farm income by $1 was 84 cents. The marginal cost of

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[5] For an application of Newton's method, see Ben-Israel [1].

Table 1. LEVELS OF FOOD AID, NONFOOD AID, DIVERTED PRODUCTION, AND TREASURY COST FOR ALTERNATIVE PROGRAMS

	Actual 1964-66 Average	Optimal Combination Under Discriminatory Payments Program			Optimal Combination Under Uniform Payments Program		
			Given 1964-66 Average of:			Given 1964-66 Average of:	
		Optimal	Diverted Production	Food Aid	Optimal	Diverted Production	Food Aid
	(Million Dollars)						
Value of Diverted Production	2724.13	3295.70	2724.13	2566.65	2625.52	2724.13	2290.19
Value of Food Aid	1473.70	565.07	1296.22	1473.70	950.03	796.47	1473.70
Value of Nonfood Aid[a]	-0-	189.07	-0-	-0-	-0-	73.50	-0-
Treasury Cost[b]	4139.53	2456.63	2646.09	2727.01	3165.02	3199.77	3318.17

[a]Untied cash aid in excess of existing levels of nonfood aid.

[b]Assumes handling, storage and transportation costs of food aid to Gulf Port were 25 percent of face value, which excludes normal CCC storage costs.

diverting $1 of production was 96 cents. The marginal cost of giving an additional dollar's worth of food aid, valued at export prices, was $1.27, which included the purchase price of $1, and the U.S.'s share of handling, storage, and transportation costs of 27 cents. The marginal value of an additional dollar's worth of food aid to the recipient countries was 53.8 cents.

Uniform Payment Diverson Program

Land withdrawal under the uniform payments program costs more than under the discriminatory payments program; consequently, greater emphasis was placed on food aid as a mechanism to dispose of excess capacity. Given the level of production diversion, treasury cost could be reduced substantially by allocating food aid according to its marginal value. Holding the value of diverted production constant at its 1964-1966 level, but allocating food aid and nonfood aid more efficiently, could reduce treasury cost 23 percent below its actual value. Treasury cost could have been reduced 20 percent by optimally allocating production diversion with the value of food aid held at its 1964-1966 level.

Treasury cost could have declined as much as 24 percent from its actual level if both production diversion (under the uniform payments program) and foreign aid had been more efficiently allocated. The optimal value of diverted production was $2,625 million, down 4 percent from its actual level. Real aid was maintained most efficiently with all food aid; the optimal value of food aid was $950 million, 36 percent less than its actual value. Cost of food aid was $963 million, and cost of production diversion was $2,202 million, for a total treasury cost of $3,165 million.

The Lagrange multipliers at the optimal combinations of production diversion, food aid, and nonfood aid indicate that the marginal cost to the government of a $1 increase in either net farm income or real aid was $1. The marginal cost of diverting an additional dollar's worth of production was $1.47, because all units diverted were paid according to the marginal unit diverted. The increase in government payments increased net farm income by the same amount; hence, at the margin this diversion program was no more efficient than direct payments in raising net farm income. The marginal cost of an additional dollar's worth of food aid was $1.26. The marginal value of one dollar's worth of food aid to the recipient countries was 46.4 cents.

Allocation of Production Diversion

Diversion of agricultural production among regions within the United States was based on the marginal cost of diversion. The optimal level of diversion was achieved by equating marginal costs within each region. The marginal cost of production diversion was $.96 under the discriminatory payments program and $1.47 under the uniform payments program. Distribution of the optimal values of production diversion are shown in Table 2.

Under both programs, the Cornbelt and Southeast had the largest values of production diversion; however, the Delta had the largest percentage of its cropland diverted. The Southeast

Table 2. **PRODUCTION DIVERSION UNDER LAND RETIREMENT BY REGION, 1964-1966**

	Cropland (1964)		Discriminatory Payments Program		Uniform Payments Program	
	Acreage[a]	Acreage as a Percentage of U.S. Total	Value	Value as a Percentage of U.S. Total	Value	Value as a Percentage of U.S. Total
	(Thousand Acres)	(Percent)	(Million Dollars)	(Percent)	(Million Dollars)	(Percent)
Southern Plains	50,723	11.43	315.54	9.57	308.29	11.74
Northeast	19,173	4.32	184.15	5.59	154.35	5.88
Southeast	47,763	10.76	509.04	15.45	497.34	18.94
Delta	20,238	4.56	366.45	11.12	358.02	13.64
Cornbelt	94,750	21.35	1030.39	31.26	663.15	25.26
Central Plains	63,305	14.26	226.32	6.87	218.76	8.33
Southwest	17,911	4.04	11.54	0.35	11.27	0.43
Northwest	19,592	4.41	50.80	1.54	49.64	1.89
Lake States	44,970	10.13	484.67	14.71	260.97	9.94
Northern Plains	65,376	14.73	116.79	3.54	103.72	3.95
United States	443,801	100.00	3295.70	100.00	2625.52	100.00

Source: [a]U.S. Dept. of Agriculture, Agricultural Statistics, U.S. Govt. Printing Office, Washington, D.C., 1968.

and Delta regions accounted for 15 percent of the nation's cropland, but for more than 30 percent of total diversion under the discriminatory payments program.

SUMMARY AND CONCLUSIONS

The study showed an efficient allocation of food aid, nonfood aid, and production control to minimize treasury cost for a given level of real foreign aid and net farm income. The production-control program considered here was a voluntary general land diversion program. Foreign aid was assumed to be given in the form of food aid or untied cash assistance, depending on the marginal cost to the United States and the marginal benefit to the recipient country. The average 1964-1966 treasury cost of farm payments and food aid, excluding normal CCC storage costs, was $4,140 million. Under the discriminatory payments program the treasury cost theoretically could have been reduced 41 percent below its actual level. The optimal solution required a 21 percent increase in production diversion and a 62 percent reduction in food aid, as well as a $189 million increment in untied cash assistance. With these optimal adjustments, real foreign aid and net farm income could have been maintained at their 1964-1966 levels. The administratively more feasible uniform payments program would have reduced treasury cost 24 percent. The optimal solution under this program required a 4 percent reduction in production diversion and a 36 percent reduction in food aid.

REFERENCES

[1] Ben-Israel, A. "On Newton's Method in Nonlinear Programming." *Proceedings of the Princeton Symposium on Mathematical Programming,* Princeton University Press, pp. 339-352, 1970.

[2] Cochrane, Willard W. "Farm Technology, Foreign Surplus Disposal and Domestic Supply Control." *Journal of Farm Economics,* 41:885-899, Dec. 1959.

[3] Pinstrup-Andersen, Per. "The Role of Food, Feed, and Fiber in Foreign Economic Assistance: Value, Cost, and Efficiency." Unpublished. Ph.D. thesis, Oklahoma State University, Aug. 1969.

[4] Pinstrup-Andersen, Per, and Luther G. Tweeten. "The Value, Cost and Efficiency of American Food Aid." *American Journal of Agricultural Economics,* 53:431-440, Aug. 1971.

[5] Shultz, Theodore W. "Value of United States Farm Surpluses to Underdeveloped Countries." *Journal of Farm Economics*, 42:1019-1030, Dec. 1960.

[6] Tweeten, Luther. "Economic Factors Affecting Farm Policy in the 1970's." *A Review of Agricultural Policy - 1970,* Agricultural Policy Institute, North Carolina State University, pp. 1-35, April 1970.

[7] U.S. Dept. of Agriculture. *Agricultural Statistics*, U.S. Govt. Printing Office, Washington, D.C., 1968.

[8] Zepp, Glenn A., and Jerry A. Sharples. U.S. Dept. of Agriculture, Unpublished data, 1970.