Economics of Remote Sensing Information

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In any survey of agriculture, two related questions usually arise. One concerns the technology used in the survey and the other concerns the satisfaction derived from the use of that technology. This paper will examine: (1) costs and benefits of remote sensing by Landsat with reference to the Large Area Crop Inventory Experiment (LACIE); and (2) cost-effectiveness of remote sensing by aircraft; and (3) will suggest a method of determining the value of remote sensing information to the grain producer.

A potential economic benefit from Landsat is the availability of timely and accurate forecast of crop production. First, we shall examine the role of the Statistical Reporting Service (SRS) of the U.S. Department of Agriculture and the potential contributions that LACIE can make to the U. S. Economy.

The Role of SRS. SRS makes estimates of crops, fruits and vegetables, other agricultural products, agricultural costs and prices, based on nationwide multipurpose surveys throughout the year. At present, the estimates have coefficients of variation (CV) of two to six percent statewide and one to three percent nationwide. The coefficient of variation of any estimate is defined as standard error of the estimate divided by the true value being estimated. SRS has developed requirements for the number of samples to obtain a specified accuracy. The sumber of samples required to obtain a CV of two percent is 500 for corn, 631 for wheat, and 463 for soybeans (ref. 1, p.4).

To estimate the production of the major crops that enter the world market, 500 to 700 sample segments may be needed to obtain CV of two percent or less. Mr. William Wigton of SRS indicated that 800 sample segments would seem to be sufficient if an estimate of the production of wheat is needed on a global basis and that 1,500 segments may be needed for estimates of other crops (ref. 1, pp. 2-4).

It costs $60 to obtain information for a single sample segment in the U. S. (ref. 1,p.4). If a worldwide sample survey were developed, the cost would become $100 or more per sample segment. This means that total cost would become $100 or more per sample segment. This means that total cost would amount to $150,000 or more (ref. 1, p.4). On the other hand, if the same number of sample segments observed by LACIE techniques were required, the cost would become $1,187 per sample segment and total cost would amount to $1.78 million, according to a preliminary estimate made by NASA Ames Research Center (ref. 2, Fig. 48).

The figure of $1,187 is substantially higher than that of $60 for a land use area sample segment. The cost of a LACIE sample segment is too high to justify the use of Landsat for one crop in a country. However, the situation may be changed when remote sensing data from Landsat are fully utilized for many crops on a global basis.

The Role of LACIE. At present, LACIE can decrease the error of estimate of area from five to two percent statewide and from two to one percent nationwide. Yield estimates can be derived from a model by means of regression analysis. Production estimates are obtained by multiplying area estimates by corresponding yield estimates. The LACIE error of the estimate of wheat production is of the order of ten percent, which compares unfavorably with the SRS error of five percent or less.

Such marginal reductions of error that LACIE can make are too costly to justify the use of Landsat. However, the real contribution that LACIE can make lies in reducing forecasting errors of the estimates of wheat production in those major wheat producing countries (Argentina,Brazil,India, China, and the Soviet Union) where substantial forecasting errors are currently being made.

The Foreign Agricultural Service (FAS) of the U. S. Department of Agriculture has calculated the errors in estimated wheat production in seven countries. These values are presented in Table 1. P(x) in column 1 indicates that the probability that a random selection of a single forecast estimate from the entire wheat producing area would be within ten percent of the final accepted value. P(x) of 0.64 for Argentina, for example, shows that the probability that a forecast estimate is within ten percent of the final accepted value is 0.64. This probability corresponds to the LACIE criterion of 64/90, which means that the estimate is 64 percent accurate at harvest, 90 percent of the time.

Very few of the estimates have satisfied the LACIE goal of the 90/90 crietrion. The only country where FSA forecasts surpassed this criterion at harvest was Australia. The quality of forecasts of wheat production made just before harvest ranged from 54/90 for Brazil to 98/90 for Australia.

Improved quality of estimates for wheat production in foreign countries are needed throughout the growing season. LACIE is capable of making production estimates involving an error approximately ten percent worldwide. At present, no appreciable reduction of error in the production estimates of wheat is possible. However, the problem of separating spring wheat from other small grains is resolved and sampling errors are reduced, LACIE could potentially reduce errors of the estimates of wheat production worldwide.

Potential Economic Benefits. The reduction of forecasting errors reduces market uncertainty and is therefore an economic benefit. A method of determining the net economic benefit to society on the basis of the consumer's surplus concept has been proposed by Hayami-Peterson (ref. 3) and developed in more detail by Arror (ref. 4). The substantial empirical work has been done by Heiss (ref. 5) and Andrews (ref. 6) of Econ, Inc. Annual benefits from global crop information,

Table 1 Forecasting Errors of the Production of Wheat at Harvest in Seven Countries 1966-75 Crop Years

Country	P(x)	1975 Production (1,000 Metric Tons)
Argentina	.64	8,570
Australia	.98	12,002
Brazil	.54	1,600
Canada	.89	17,078
China	n.a.	38,700
India	.88	24,235
Soviet Union	.65	66,144
Total		168,329

Note: P(x) is the probability that a random slection of a single forecast estimate from the entire wheat producing area is within ten percent of the final accepted value.

Source: Warren, Fred. Forecasting Errors of U.S.D.A. Wheat Estimates for Seven Foreign Countries 1966-75, Foreign Agricultural Service of the U.S. Department of Agriculture, June 1977.

according to Heiss and Andrews, range between \$200 and \$250 million for wheat, between \$50 and \$100 million for corn, and between \$6 and \$11 million for soybeans. Significant parameters that influence estimates of benefits constitute the price elasticities of demand, the price elasticities of supply and the interest rate. Price elasticity is defined as a percentage change in the quantity demanded (supplied) divided by a percentage change in the market price.

The above calculations by Heiss and Andrews raise several serious questions. First, the assumption that a forecast based on Landsat data of world wheat production reduces market uncertainty is unrealistic and cannot be taken for granted. The producer is a price-taker and has absolutely no control over the two things that affect his cash flow - the weather and the Chicago grain exchanges where deals in the future set the prices for the producer. Neither does the consumer have the power to influence the price of grain. Even if information on estimates of grain production is available to everyone, such information has little value to the producer and to the consumer. Information becomes valuable only if the information can affect action on the part of information seekers. If the information does not affect action, it is of no value. Thus the assumption of pure competition in which everyone is equal in knowledge and power cannot be justified.

Second, Heiss and Andrews have failed to make an absolutely essential distinction between perfect information and better information. The former eliminates uncertainty in full while the latter does not entirely eliminate uncertainty. Failure of this distinction overestimates net benefits. A simple example illustrates the point.

Table 2 compares benefits due to perfect information with those due to better information. The probability that better information on estimates of world wheat production is within ten percent of the final estimates is 0.9. The amount of benefits varies with the quality of information and with the degree of forecast errors reduced.

The amount of benefits in 1977 is almost half that of benefits in 1975. The difference is due to the average price of wheat and the quantity of U. S. export of wheat.

Third, no attempt has been made by Heiss and Andrews to distinguish between aggregate benefits and individual benefits. This distinction is again of vital importance to different information seekers. Under imperfect competition, as opposed to perfect competition, a simple summation of individual benefits doe not lead to aggregate benefits due to external diseconomies. External diseconomies are negative economic effects of one producer on another. Discharge from a chemical plant, for example, pollutes air and water and thus has negative economic effects on producers and consumers in the surrounding area.

Table 2 Estimates of Economic Benefits Due to the Reduction in Error of Forecast of U. S. Wheat Export in 1975 and 1977

(Millions of Dollars)

Type of Information	1975 Reduction in Errors 5%	1975 Reduction in Errors 10%	1977 Reduction in Errors 5%	1977 Reduction in Errors 10%
Perfect Information	$73.7	$294.8	$40.8	$163.1
Better Information with probability of 0.9	59.7	238.8	33.0	132.2

Note: The formula employed here is the same as that employed by Heiss and Andrews.

Source: Foreign Agricultural Service of the U.S. Department of Agriculture. Foreign Agricultural Circular: Grains, June 13, 1977.

Cost-Effectiveness. Cost-effectiveness is another way of examining economic benefits when the level of benefits is the same. In his memorandum No. 1822, August 13, 1973, the Secretary of Agriculture requested that the Department's users, who could potentially benefit from remote sensing, be identified.

The data needs of the U. S. Department of Agriculture are enormous and diversified, ranging from individual crop coverage at specific intervals to general land use classfication. The number of departmental users amounted to 3,078 and the number was reduced to 1,378 when data redundancy was eliminated (ref. 7,p.77-3092).

Only 110 users will be satisfied with Landsat I, II, or C at 80 meter resolution (ref. 7, p.77-3092). This figure will increase when resolution increases to 30 meters in the early 1980s (ref. 8, p.26). The remaining 80 percent of users will not be satisfied with Landsat C or D. These users need resolution greater than 30 meters.

The cost of acquiring remote sensing data is determined in part by the required resolution which, in turn, depends on certain performance parameters. These performance parameters are altitude (which determines instantaneous field of view, swath, and resolution with a given camera system), crusing speed (which determines area covered per unit of time), and cost of operation (which helps determine cost per unit area coverage).

Acquisition costs of airborne survey data are presented in Appendix Table A and a summary of these costs is shown in Figure 1. The figure shows that the Sabre 60 is most cost-effective in aquiring data when the resolution is less than five meters. It is most expensive to aquire the same data by means of twin engine propeller driven aircraft. To obtain infrared color film positive of one square nautical mile area with a resolution of 3 to 5 meters with the Sabre 60 aircraft costs \$.57. When less than one meter resolution is required, the cost rises to \$1.51, almost three times as much as that of 3 to 5 meter resolution. This indicates that the economic benefits derived from high resolution films must be almost three times as high as those from 3 to 5 meter resolution.

When resolution is in the range between 80 and 100 meters, Landsat is most cost-effective (12¢ per nautical square mile). However, the figure does not include the capital investment cost and includes only the cost of film processing. When Landsat is commercialized in the private sector of the economy, the cost of acquiring Landsat data will increase by a substantial amount.

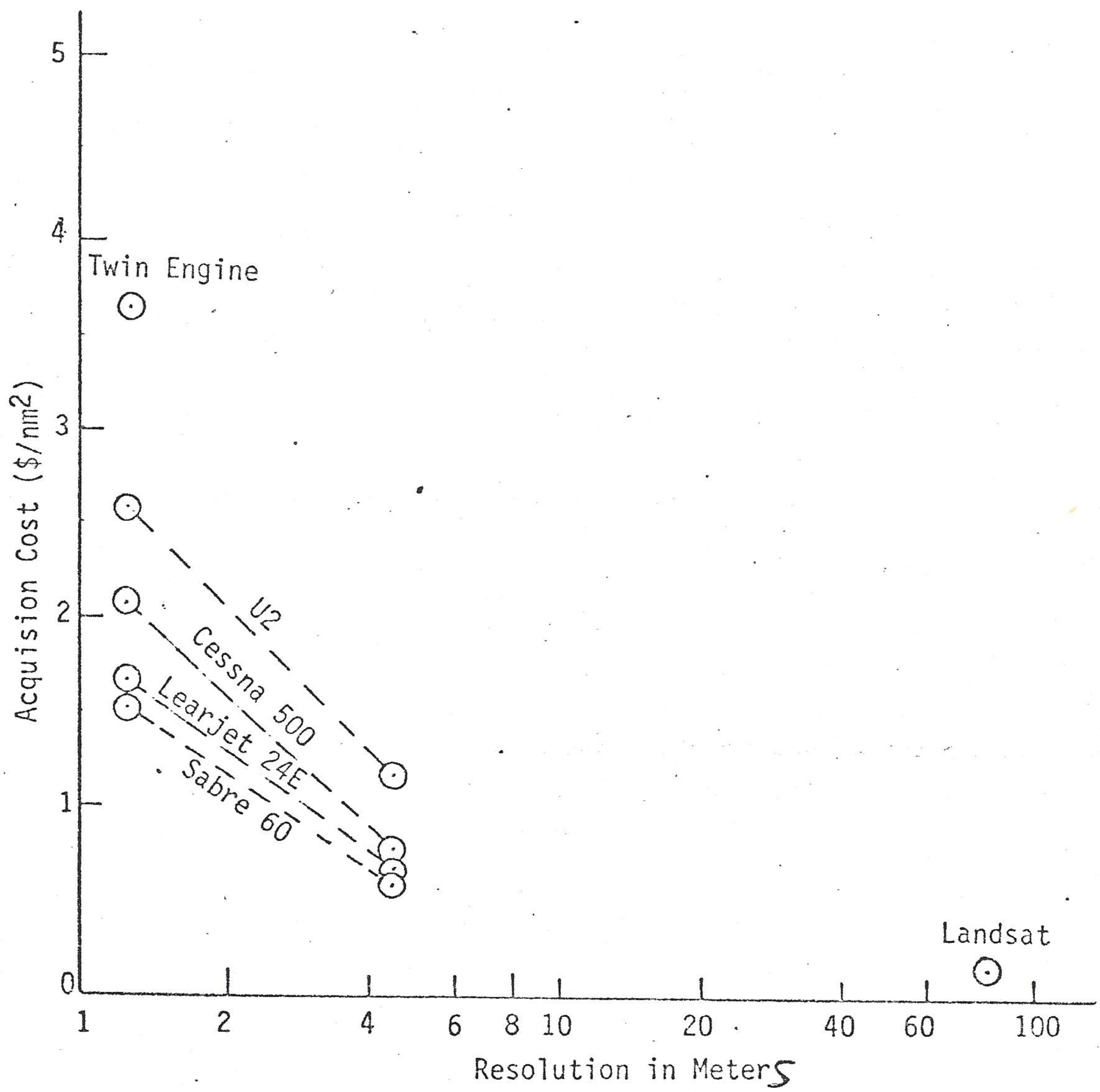

Fig ACQUISION COSTS OF REMOTE SENSING DATA BY TYPE OF AIRCRAFT

Value of Information. The real dollar benefit of remote sensing information to the producer is a function of the cost of information and of the increase in profit that results from the information. For example, if the producer obtains accurate information on the price of wheat (soybeans) in advance, he could maximize his profit. The question is - Is such a system of perfect information cost-effective?

The most important thing that the producer would like to know in advance is the price he can expect. If, for example, the producer knew that the price of wheat (soybeans) would rise, he could then increase his profit by planting more wheat (soybeans).

Even though perfect information on the production of wheat and soybenas is available worldwide, the probability of a price increase or decrease would not be known, but could be estimated on the basis of agrometeorological and economic data. The producer could then maximize his expected profit on the basis of these probabilities. Let us take a hypothetical example. If the producer were to determine from agrometeorological data that the probability of a price rise of wheat were high, then he could take action A (more acres of wheat with the consequence of the increase in profit). On the other hand, if the probability of a price rise of soybenas were high, he could take action B (more acres of soybeans with the consequence of the increase in profit).

The value of information can now be defined as the difference between the profit with perfect information and the profit of the best possible action with imperfect information.

The above framework would permit the producer to utilize information on the expected price of wheat (soybeans) and to maximize his profit under uncertainty. It would also permit him to estimate the value of perfect information. However, the actual price the producer is willing to pay is always lower than the price determined by perfect information. A simple example is given in Table B.

This method would be of value. It is, therefore, recommended that information from remote sensing (LACIE and other) be translated into a meaningful form to the producer, utilizing the above framework. At the very least, the potential value of such a framework may justify testing the model.

Table B Decision Matrix

Event	Probability	Action A	Action B
		Profit per acre	
Price of wheat, PW	P_w	R_{wa}	R_{wb}
Price of soybeans, PS	P_s	R_{sa}	R_{sb}

$P_w + P_s = 1.0$

Note: The producer is assumed to allocate crop land into wheat and soybeans in order to maximize his expected profit. If the profit from wheat were larger than that from soybeans, action A would be taken. A large (small) portion of land would be allocated for the production of wheat (soybenas). Conversely, if the profit from soybeans were larger than that from wheat, action B would be taken. A lerge (small) portion of land would be allocated for the production of soybenas (wheat).

The expected value of profit resulting from action A is

$$E_a = P_w R_{wa} L_w + P_s R_{sa} (L - L_w)$$

where L_w = acres of wheat land; and L = total crop land.

The expected value of profit resulting from action B is

$$E_b = P_w R_{wb} L_w + P_s R_{sb} (L - L_w).$$

The best possible action, referred to on page 8, is defined as E_a or E_b whichever the higher.

If the producer knew for sure that profit from wheat (soybenas) were larger than that from soybens (wheat), he would plant wheat (soybenas) only. Then the expected profit with perfect information E_p is defined as

$$E_p = P_w R_{wa} L + P_s R_{sb} L.$$

The value of perfect information, E_I, is now defined as the difference between profit with perfect information and profit from the best possible action under uncertainty,

$$E_I = E_p - (E_a \text{ or } E_b \text{ whichever the higher}).$$

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Appendix: Table A Acquisition Costs of Infrared Color Film Positives, Using Different Aircraft-Camera Systems

Aircraft 1) Altitude 2) Crusing Speed	U-2 1) 65,000 ft 2) 400 nm/hour	Cessna 500 1) 40,000 ft 2) 325 nm/hour	Learjet 24E 1) 45,000 ft 2) 425 nm/hour	Sabre 60 1) 45,000 ft 2) 430 nm/hour	Twin Engine 1)7,000 ft 2) 150 nm/hour
Camera System: 6" focal length; 9" by 9" film size					
Resolution(m)	3 to 8	2 to 5	2 to 5	2 to 5	0.3 to 0.8
Image area 50% overlap(nm^2)	128	50	56	56	1.5
Coverage rate 40%(nm^2/hour)	2,300	1,100	1,620	1,650	232
Aircraft operating cost($/hour)	2,000	200	378	300	200
Film cost($/$nm^2$)	0.28	0.59	0.39	0.39	2.80
Aircraft cost($/$nm^2$) ($/nm^2)	.87	.18	.23	.18	.86
Total Cost($/$nm^2$)	1.15	.77	.62	.57	3.66
Camera System: 24" focal length; 9" by 18" film size					
Resolution(m)	0.6 to 3	0.5 to 2	0.5 to 2	0.5 to 2	
Image area 50% overlap(nm^2)	16	6	7	7	
Coverage rate 40%(nm^2/hour)	1,150	555	810	825	
Aircraft operating cost($/hour)	2,000	200	378	300	
Film cost($/$nm^2$)	.83	1.71	1.17	1.15	
Aircraft cost ($/$nm^2$)	1.74	.36	.47	.36	
Total cost($/$nm^2$)	1.57	2.07	1.64	1.51	

Source: Arno, Roger D.: An Analysis of the Aircraft Program Segment of the U.S. Department of Agriculture Remote Sensing Survey Goals, NASA Ames Research Center, September 1976. (Preliminary)