THAYER WATKINS
San Jose State University
San Jose, CA 95192

The Economics of Remote Sensing*

Papers on remote sensing of vegetation, presented at the First and Second Conferences on the Economics of Remote Sensing Information Systems, are summarized.

WHAT I WILL ATTEMPT to do in this paper is summarize, with a little interpretation, the papers on remote sensing of vegetation which have been presented at the First and Second Conferences on the Economics of Remote Sensing Information Systems, held at San Jose State University. Those Conferences were intended to bring together people who were concerned with making decisions involving remote sensing. It was hoped that the papers would provide reference documents on methodology and parameter estimates for others undertaking similar studies.

At the San Jose Conferences few papers were presented on the economics of vegetative damage assessment, *per se*. However, the economics of this particular topic fits into the general scheme of the economics of information and some results, particularly concerning methodology, are applicable. The economics of information divides into the elements of costs and benefits, with the benefits much more difficult to estimate satisfactorily than costs. The benefit of information at the simplest level is the improvements which can be achieved with the better decisions, such as for planting, made possible by the information. Improvements referred to in the previous statement would include any achievement of higher levels of consumption or reduced costs to members of the economy. In the case of crop damage assessment, the value lies in being able to adjust over a longer period to less than expected production by means of increased plantings, foreign purchases, or reduced consumption.

* Invited paper, Symposium on Remote Sensing for Vegetation Damage Assessment, Seattle, Washington, February 14-16, 1978.

The economic theory of measuring costs and benefits of some change is complex but a brief sketch of the principles can be given. Usually the measurement of benefits and costs is conducted with respect to a specific project but it could be done for any change.

The first principle is that the benefits and costs should be evaluated for the impacts of the project where *impact* means the difference between economic conditions with and without the project. For example, the impact of a project may be the increased production of food achieved by the project.

The second principle is that economic benefits and costs of impacts are expressed in terms of the amount of money which would be equivalent in its effect on those affected.

The third principle is that for small changes in the output of a product the value to a user of a product is equal to the price which users had been paying times the change in output, i.e., its market value. This holds because users will increase their purchases up to the point where an additional unit of the goods, say a pound of coffee, is of no more or less benefit than the money given up, the price, to get it. If the additional pound of coffee were worth more than the price, the user would increase his use and if it were worth less he would reduce his use. Thus, the marginal benefit of an additional unit is equal to the market price. This holds true for all users whether their preferences are such that they use a lot or a little.

The above applies strictly for infinitesimal changes. If the impact is too large as compared to the existing situation to be considered infinitesimal, then a modification must be introduced. The total use of a commodity depends upon its price relative to that of

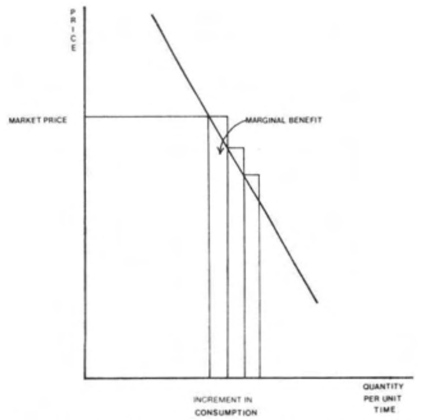

FIG. 1. Marginal benefit as area under demand schedule over the range of the increased output.

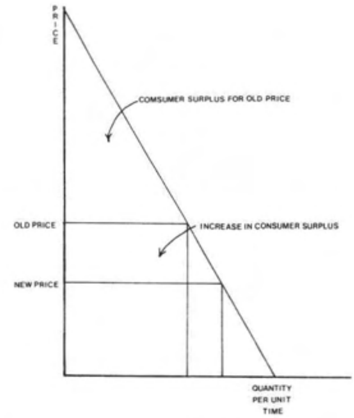

FIG. 2. Consumer surplus as net benefit to user of being able to purchase goods at a given price.

other goods. This relationship between the quantity demanded and the price, all other factors being held constant, is called the demand schedule or demand curve. The demand schedule contains much important information such as the inverse relationship between the price of the product and the quantity put on the market. When a finite change in output is considered as being made up of a sequence of minute changes, it can be shown that the gross benefit to the users of the finite change is equal to the area under the demand schedule over the range of the finite change. This is the fourth principle of the measurement of the benefits. This is illustrated in Figure 1.

The above can be extended to show that the gross benefit to users is the area under the demand schedule from zero up to the level of use. But this is the gross benefit to the user. The net benefit must take into account that the user had to pay money to get the level of use he desires. The net benefit which in economics is called *consumer surplus* is the area under the demand schedule and the market price line as is illustrated in Figure 2. This quantity has the dimensions of income and represents the value to the user of being able to buy the goods at a definite market price. The value to the user of a reduction in market price is measured by the increase in consumer surplus. This is the fifth principle of the measurement of benefits.

There are other approaches to measuring benefits but the above constitutes the mainstream of economic thought. Because of the difficulty of measuring benefits frequently, analysis is limited to comparing the cost of alternate methods of achieving the same results (and benefits). Such analysis is called cost-effective analysis as contrasted to cost-benefit analysis.

Costs are easier to measure than benefits but some principles must be adhered to. First, the real costs of a project are the amounts of resources which are made unavailable for other uses because of the project. The alternate uses for the resources are the opportunity costs of the project. The value of the alternate products which could be produced with the resources will be, for marginal changes and under competitive conditions, equal to the market cost of these resources and resource services. The relevant costs are thus the incremental costs. A troublesome problem which often arises is how to allocate joint costs, costs which are common to several projects and which would be incurred even if one of those projects were eliminated. Accounting can come up with some perfectly reasonable methods for sharing these joint costs among projects but economic analysis indicates that any such allocation is essentially arbitrary.

Some of the most sophisticated analyses of the economic benefits of remote sensing have been carried out by the economic consulting firm, ECON, Inc. under contract with NASA. This work started in 1973 and special attention has been given to wheat. F.Sand presented a paper last year covering the econometric measurement of benefits of information systems in the wheat market. The model used was an extension of the Hayami-Peterson (1972) model. This was a two-seasonal model in which erroneous forecasts result in deviations from optimal consumption. The benefits from increased consumption in the pre-harvest or post-harvest period do not cancel out decreased

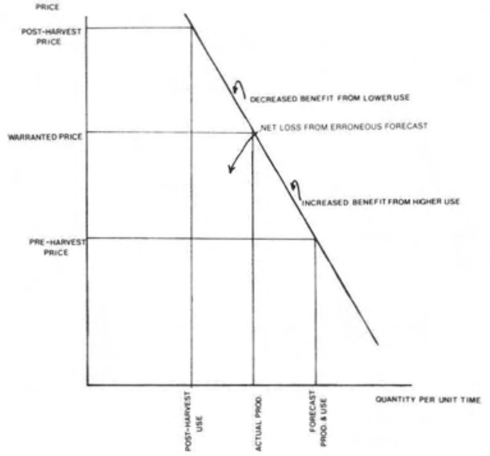

FIG. 3. Hayami-Peterson method of computing social loss from erroneous forecast.

benefits from the corresponding deviation in the other period (see Figure 3.) The ECON, Inc. model allowed for dynamic adjustment. The logic of Sand's analysis is that improved wheat forecasts lead to more stable prices and consequently better production, storage, and trade decisions. The improved decisions lead to increased supply and improved prices for wheat users. It was assumed that all information concerning wheat production is available to the public so that none of the benefits accrue from the differential availability of information. In economic terms, the benefits accrue from a downward shift in the supply function for wheat. This results in lower prices to the consumer (increased consumer surplus) as well as cost savings to producers.

Sand used data from 1960 to 1974 to confirm estimate-model parameters, and the benefits were estimated for the period 1968-1972 exclusive of the infamous Russian wheat deal. Annual benefits to the U.S. were \$150 to \$250 million compared with his estimated annual costs for Landsat of \$60 million. The major part of the benefits was due to improved forecast accuracy in the USSR, India, and southern hemisphere countries. K. Heiss, a principal in ECON, Inc., addressed the issues of how to quantify the economic benefits of more timely and accurate information. One particularly interesting issue he pursued is whether the U.S. might be better off without the improved forecasts if they are made public. He concluded that there were major benefits to the U.S. of improved public forecasts.

A critical review of three estimates of benefits from Landsat programs was presented by D. Ray and K. Keith of Oklahoma State University. Two of the studies reviewed were prepared by ECON, Inc. and the other by Earth Satellite Corporation. Ray and Keith concluded that the models used by ECON, Inc. did not allow for the proper mechanism of adjustment to an improvement in forecasting accuracy and that the assumptions of the accuracies which could be achieved with Landsat data were overly optimistic. The point of how to translate engineering specifications for remote sensing equipment into measurement accuracies was addressed by K. Stow of the General Electric Space Division in a paper presented at the Second Conference. G. Hart of the USDA Statistical Reporting Service (SRS) presented some quantitative estimates of the accuracy improvements which can be achieved using Landsat data. The SRS conducts a statistical sampling to obtain crop estimates. The sampling program produces major crop estimates with a relative sampling error of 1.5 to 3.5 percent at an annual cost of \$3.5 million. He reported the results of an experiment combining the SRS 16,000 enumeration units sample with the more extensive coverage over time and space with Landsat data. The trial was carried out on Illinois data. There were problems with the coarseness of spatial resolution, the difficulty of extracting land-use information from reflectance data, and cloud cover. Combining the two data sources involved

- Registering sample unit locations to Landsat Computer Compatible Tapes (CCT),
- Locating field boundaries in CCT's,
- Tagging individual pixels with ground enumerated land use,
- Establishing relationships of reflectances to land use for sample units,
- Classifying all pixel data, and
- Developing regression estimates.

The costs of the procedures required for combining the data sources are given by G. Hart as 100 person-hours for registering a scene of 40 sample units with 50 control points, 40 person-hours for locating field boundaries, and classification cost of \$2,000 for computer time. The correlations between ground and Landsat data were in the range 0.6 to 0.8. The relative sampling error for the corn acreage estimates in the Illinois study was 3.6 percent using only sample data and 2.5 percent using regression estimates from the combined sources. Cost of the program was \$120 thousand.

J. Nichols of ESL, Inc. reported on the performance of multi-stage sampling schemes utilizing remote sensing data (in this case ERTS data tapes and aerial photographs) for estimating timber volume. In the Plumas National Forest, Nichols reported that the cost of achieving timber volume estimates with an allowable error of 10 percent with the multi-stage sampling were only one-third that of conventional sampling procedures not using satellite data. For the Forest Inventory Study of Western Washington the cost of achieving a given allowable error was less than half the cost of conventional methods.

D. Morse and J. Sahlberg stated that, in the Idaho Snake River project for estimating irrigated acreage, the Landsat-aided data collection system cost about two-thirds that of the next best alternative (Lear-Jet). In the monitoring of irrigated land in the Klamath River Region of Oregon, the Landsat-aided system cost approximately 50 percent of that of the next best alternative of the same accuracy. These figures do not include the capital cost of the satellite system or its full operating cost.

W. Enslin and R. Hill-Rowley provided detailed cost information on mapping forest resources in Mason County, Michigan using color-infrared photography. The results could be used to select areas of concentration of marketable timber types. Another application of forest resource evaluation by remote sensing is available in the First Conference Proceedings prepared by R. Mroczynski and T. Lyons for Indiana.

Some of the papers presented at the Conferences made cost comparisons between aircraft and satellite data sources, but it quickly became clear that in many cases it was not a matter of either aircraft or satellite but of how to optimally amalgamate the alternate sources into the best information system. There are, however, some instances in which cost comparisons of alternative data sources are appropriate. K. Craib, who was responsible for initiating the San Jose Conference, developed an interest in the economics of remote sensing partly as a result of a study carried out by his firm, Resources Development Associates, on cost and effectiveness of alternate techniques for soils and land-use surveys in Honduras. The experimental studies compared panchromatic color, color-infrared, multi-spectral photography, and Landsat imagery, all manually interpreted with simple photo-interpretation equipment. In addition, alternate collection schemes such as total coverage and strip sampling were compared. The results indicated that

- Equal accuracy of soils survey could be achieved with stereo color infrared or color photography. A close second in accuracy was achieved with stereo panchromatic black-and-white photography.
- Additive color multispectral photography was not suitable because of a lack of stereo viewing capability.
- Soils interpretation could be performed in 30 percent less time with color-infrared than with panchromatic.
- Land use could be interpreted most accurately with stereo color infrared and in 50 percent less time than with panchromatic photography.
- The least expensive data collection method, panchromatic photography, resulted in the most expensive overall program and produced less accurate results.

T. Cannon, another member of Resources Development Associates, presented a paper on resource inventory assessment in Costa Rica where there is a problem of monitoring the conversion of forest to range land. The program utilized low- and medium-level aerial photographs (natural color and color-infrared) to obtain data on forest cover and Level I land use classifications. R. Ellefsen, of the Geography Department at San Jose State University, presented a separate paper on the monitoring of urbanization in Costa Rica. On the problem of forest conversion, Cannon concluded that

- Remote sensing can meet most but not all resource assessment needs;
- Project design is of paramount importance for utilizing remote sensing as a data source;
- Present satellite systems are not adequate for preparation of a resource data base whereas aerial photography will meet the majority of requirements for a data base; and
- Satellite systems are able to provide useful information for monitoring a resource assessment program.

F. Mertz of the Geography Remote Sensing Unit of the University of California at Sanata Barbara presented a paper demonstrating the feasibility of obtaining vegetative cover data for an input to a watershed run-off model for Kern County, California. Mertz reported that the necessary data were obtained from Landsat-2 at 10 percent of the cost of conventional sources. A survey of remote sensing applications in Canada was presented at the First San Jose Conference by A. McQuillan of the Canada Centre for Remote Sensing. One interesting application was in the determination of frost-prone areas in the Niagara fruit belt. This project is to use airborne thermal-infrared scanner data to determine optimal fruit varieties. A grape conversion program has been going on since 1975 and some areas must be replanted with more frost-resistant varieties. Annual benefits in the range of $100 to $200 thousand seem reasonable, according to McQuillan.

McQuillan also presented estimates of the value of increased accuracy of wheat forecasts for Canada. He estimates that a reduction of the margin of error of forecasts of Canadian wheat production from 5 to 4 percent would result in increased export earnings for Canada of $7 million per year. A reduction of the margin of error for world wheat production from 10 to 7 percent would increase Canada's export earnings by $78 million per year.

Two papers on economic applications of remote sensing were presented by principals in the firm of Ecographics of San Diego, R. Brown, Jr., G. Rhoades, and T. Foresman. One paper compared the cost of monitoring fire damage and recovery at Camp Pendleton and Vandenberg Air Force Base using conventional methods and Landsat data. The cost of the Landsat-based information was approximately one-fourth that obtained by conventional methods. In an extremely skillfully presented paper R. Brown demonstrated that a near-infrared band can be used to map the kelp forest mats on the ocean surface at a fraction of the cost of current methods.

R. Arno of NASA's Ames Research Center has presented two papers giving details of costs in remote sensing programs. In his first paper he developed some very interesting quantitative information on the trade-offs between programs costs and resolution for various aircraft systems and satellite data sources.

As more cost and performance data are accumulated on various systems and on methods of combining them, it will be easier to design optimal information systems for specific project needs. H. Huddleston presented a paper on monitoring agricultural land cover for state-size geographic regions. This study involves elements of system design. Hopefully, future conferences on the economics of remote sensing information systems will assist in sharing pertinent design information.

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