Use of Spatially Referenced Data in Agricultural Economics Research

Tihomir Ancev*, Inakwu O.A. Odeh**

Abstract: Georeferenced data on biophysical and socio-economic attributes are increasingly being used for decisions regarding priorities of land uses. However, research on the methodological approaches to using spatially referenced biophysical digital data in agricultural and resource economics is limited. Whether this is due to a failure to recognise the full versatility of these data or to some genuine limitations imposed by the data is one of the questions this article addresses. We also review some recent developments in the field and point to research directions in the use of such data in agricultural and resource economics as well as the choice of empirical approaches, such as econometric or programming models, static or dynamic models, and stochastic or deterministic models.

Key words: integrated modelling, research directions, spatial econom(etric)ics.

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* Discipline of Agricultural and Resource Economics, Faculty of Agriculture, Food and Natural Resources, University of Sydney, Sydney, NSW, 2006

** Discipline of Agricultural Sciences, Faculty of Agriculture, Food and Natural Resources, University of Sydney, Sydney, NSW, 2006

Introduction

The focus of this paper is on digital spatially referenced data and their current and potential use in agricultural, resource and environmental economics. Such digital data can be readily incorporated in Geographic Information Systems (GIS) which are in turn suitable for economic analysis. Thus, main interest of the paper is in the GIS facilitated use of digital spatially referenced data in agricultural and resource economics research.

There is not a single definition of digital spatially referenced data. One definition may be that a digital data set of some attributes of interest on the Earth surface is spatial referenced if it has associated spatial locations, defined by a coordinate system, presented in a computer storable format (DWG, DXF, shape file format etc.). Examples of such data of interest to agriculture in general and agricultural /resource economics in particular are: digital soil maps, Digital Elevation Models (DEM), climatic data, land use data, river flow data, agricultural census data, etc.

The digital spatial data provide interlink between the economics and geo-sciences (including soil and agricultural science). This link can be established through several perspectives. One is to incorporate spatially referenced biophysical data in the economic modelling. This aspect is a predominant subject of the current paper. Another perspective is to incorporate economic variables in geo-scientific research. This is especially in relation to land use change studies, where economic variables such as demographic factors, farm incomes, agricultural commodity prices, education levels, and others can play a significant role in explaining the patterns of land use change.

The objective of this paper is to overview the literature on the use of spatially referenced data in economics research and to point to some gaps and unexploited opportunities, all in an attempt to (re)introduce the possibilities of using such data to the Australian agricultural and resource economics profession. The motivation for preparing this paper was the attendance by one of the authors to an organised symposium titled "Microspatial Analysis Methods for Modeling Agricultural and Environmental Interactions" during the 2004 American Agricultural Economics Association meeting in Denver, Colrado. An impression from the presentations was that agricultural economists are still cautious of using GIS data.

Based on this premise the paper is focused on how georeferenced human activities in agriculture, or more generally in natural resource management, can be used in answering questions of interest to agricultural and resource economists. As an extension, the paper explores the economics of the effects of georeferenced activities on the environment. The following section summarises the relatively short history of literature on the use of spatially referenced data in agricultural, resource and environmental economics. This is followed by a very brief overview of the nature of spatially referenced data. The theory section outlines alternative theoretical approaches to integrating geo-spatial and agricultural economics research. Next, some methodological issues pertinent to the alternative approaches are discussed. The penultimate section presents briefly several case studies that the authors have undertaken or plan to do so in near future. The concluding section wraps up.

Literature Review

The literature on the use of remotely sensed data in agricultural and resource economics research received an impetus through an US EPA funded project on Patuxent catchment in the state of Maryland, USA (Bockstael, 1996). This project resulted in numerous publications (Geoghegan, 1998). The project had an objective to explain the land use changes in this diverse catchment by statistical modelling, including physical and economic variables (Bockstael, 1996).

Somewhat around the same time, the field of spatial econometrics developed with the works of Ansellin (1988 and 2001). From agricultural economics viewpoint, spatial econometrics recognises the spatial component in agricultural data (predominantly experimental data) and devises statistical methods for modelling. This is somewhat in line with the usual approach aimed at controlling spatial variation, for example by Fisherian blocking in experimentation. However, it appears that this spatial variation has to offer more than being just a nuisance that has to be taken care of. Geoscientists and soil scientists are indeed predominantly interested in the spatial features of the landscape and soils and want to investigate them, rather than simply to control for the effects of spatial variation. In spite of some criticism, spatial econometrics remains an important methodological approach in analysing various economic phenomena in agriculture, geography, land use etc.

Maybe because of the nature of the pioneering Patuxent catchment research that explored the reasons for land use change, a substantial literature has followed this topic. The literature has predominantly used probability models (logit, probit) in an attempt to model the changes in observed land uses as a function of various variables, including economic, physical and biological (Bokstael, 1996; Geoghegan et al., 1998; Nelson and Geoghegan, 2002; Holloway et al., 2002; Bell and Irwin, 2002). The models presented in these studies were used to compute the marginal effects of the explanatory variables on observed land use choices and to simulate the effects of policy change. This stream of literature has been quite prolific over the recent years (Table 1). It seems however, that too much focus has been given to the land use change research on the expense of other potentially relevant research approaches.

For example, spatially referenced data can find useful application in environmental and resource economics. A very good overview of the use of GIS in environmental and resource economics literature is provided in Bateman et al., 2002. The surveyed applications are predominantly related to environmental valuation methods. Spatial referencing is a corner stone of the hedonic pricing method (Bastian et al., 2002) and the development of GIS computer platforms can significantly facilitate and improve the hedonic modelling of property prices as a function of certain environmental amenities. Further, the development of digital road network maps and their incorporation in the travel cost method can greatly improve the accuracy of estimates of travel times and distances (Bateman et al., 2002). An additional application is in relation to benefit transfer. Since contingent valuation studies are expensive to conduct, it would be desirable to be able to transfer the estimates of the demand for environmental amenities from a site that has been subject to a contingent valuation study to a site for which we want to make decisions. This is referred to as benefit transfer (Loomis, 1992). There are several criteria to determine if such transfer is possible (Desvouges, Naughton and Parsons, 1992), an obvious one being that the two sites have to be similar in terms of geography, biology, land use etc. Spatially referenced GIS data can clearly be used to make such comparisons more amenable.

Another field that has not received great attention in the literature is the possibility to use spatially referenced data in an economic optimisation framework. Optimisation methods can be used to conduct economic analysis about land use changes, environmental consequences of agricultural activities, effectiveness of conservation programs etc. (Ancev et al., 2003; Khana et al., 2003).

Both econometric methods and optimisation methods can be used in conjunction with biophysical methods to be able to derive more integrative results and propose more holistic policy recommendations. The use of such joint biophysical and economic modelling is increasing (Ancev et al. 2003; Ancev et al. 2004; Tanaka and Wu, 2004).

The following table summarises the main literature contributions and the various possibilities to use GIS data for agricultural resource and environmental economics research. [Table 1, here].

Basics of spatially referenced data

Spatially referenced data comprise of information about properties of the objects of interest that are spatially referenced to a (usually small) portion of the Earth. For example, if one is interested in the altitude of a particular mountain or hill, the spatially referenced data describing it could be digital elevation measurements or digital elevation model (DEM) with their specified locations defined by a coordinate system (e.g. geographical coordinates of longitude and latitude, or local datum coordinates system of easting and northing). Getting the location coordinates of objects in difficult-to-access regions of the globe can be very difficult. An alternative for obtaining georeferenced data for such locations is through remote sensing. Remote sensing can be defined as gathering of information using aerial or space-borne sensors or satellite instruments. For a rather instructive but yet brief introduction on remotely-sensed data see Nelson and Geoghegan (2002). Much more in-depth references are the numerous GIS and remote sensing text and research books (e.g. De Mers, 2004). The earliest form of remote sensing is the aerial photography which preceded the space-borne remote sensing with the emergence of photographic cameras and balloons late in the 19th century. The space-borne remote sensors, which are predominantly carried by satellites comprise of instruments that sense solar reflections from the surface of the earth registered by satellite mounted sensors measuring the intensities of different frequencies of the light spectrum. A few others are active sensors that direct signals onto the earth's surface and record the back reflectance.

Spatially referenced data collected through remote sensing or by ground-based[1] observations (Table 2) are often used and applied in Geographical Information Systems (GIS). There is no universally acceptable definition of GIS, but a working definition will suffice here: GIS are tools (systems) for capturing, storing and processing of spatial data into information that is referenced to the Earth (Bateman et al., 2002; De Mers, 2004). The spatial referencing can be done through either of the two data formats. One is where the observations of interest are referenced to a land area – raster data format. The data is usually referenced to a small block of the earth surface, which is sometimes called a cell or a pixel. The size of these areas is commonly 30 by 30 meters but can go as low as 1 by 1 meter. This is called the spatial resolution of the raster data. Obviously, the finer the resolution, the smaller the portion of Earth the data is referenced to, and hence the more precise the referencing. Even though this type of raster data is not completely exact, since

[1] Indeed, a number of studies have used what is known as supervised land use classification that combines remotely-sensed data with data collected on the ground (ground truthing).

it assumes no variation within the pixel, it is practical and quite precise at higher resolutions.

When the spatial referencing is done so that a single point on the earth surface is referenced, the collected data is said to be in a vector format. Vector data is collected and stored as values of *x* and *y* coordinates. These coordinates refer to a planar coordinate system that is obtained by projecting the earth sphere onto a plane. For the types of projections and the involved techniques see some GIS reference (e.g. DeMers, 2004). Vector data format is suitable for mapping of discrete geographic and other physical features, for which their exact location is of defining importance (streets, shire boundaries, parcels etc.). Within the vector data format, the mapped features (points, lines, polygons) have linked attribute table, describing the attributes of these features.

The origin of the coordinate system used to reference vector data is of paramount importance. The origin of the system is called a geodetic datum, which defines the size and the shape of the referenced portion of the earth, as well as the orientation of the coordinate system. The usual orientation is North on the vertical axis and East on the horizontal axis. Hence, the terms northing and easting that we often encounter, but not always understand. They just represent the distance (in meters) to the north and east from the selected geodetic datum, and serve as *x* and *y* coordinates.

Table 2 shows some sources of older and newer remotely sensed and other spatially referenced data that are, and could potentially be used in biophysical and economic modelling. [Table 2 here].

Theoretical considerations

There are two main paradigms to interlinking remotely sensed data and economics. One is the “data mining”– mining the pixel (Geoghegan et al., 1998), and the other is economic modeling using the data provided by remote sensing or the GIS. The former attempts to identify some economic meaning in GIS digital imagery, like finding and linking some economic variables, such as land prices, proximity to urban areas, or farming income, to the observed landscape changes. The latter paradigm often involves more complex procedures. One way of using spatially referenced data in economic modelling is through construction of probabilistic models of changes in economic behaviour (crop choice, changes in agricultural practices etc.). Another possibility for economic modelling is through optimization, either directly using remotely sensed data, or in the case of the research on environmental effects from agriculture, indirectly through various biophysical simulation models. This type of modelling usually involves a “social” objective function, in the sense that either social welfare (including externalities) are maximized or social costs (including private and external costs) of meeting given policy targets are minimized. Based on the specified objective function and the underlying constraints, the optimization techniques (linear, non-linear, dynamic, stochastic and positive programming) can be used to derive “socially” optimal layout of land use in a given area. Even though such “socialization” may be controversial and not easily accepted, it offers valuable insights into the effects of current policies and the desirable directions of future policies.

This dichotomy of possibilities for integrating spatially referenced data in agricultural and resource economics modelling appears to resemble the iconic dichotomy in economics, the one that distinguishes between positive and normative economics. While the etymological meanings of the words suggests that the former is somewhat more desirable than the later, often tempting young economists to blindly follow the better sounding one, an experienced economist should know that both approaches are quite useful for specific purposes and the choice between the two has to be made based on the context. Sometimes, the problem at hand might be such that the positive, descriptive approaches are needed (statistics, econometrics) and other times the problem is such that normative, prescriptive methods are warranted (optimisation, programming). In what follows, the main theoretical concepts behind these two approaches, in particular with relation to the use of spatially referenced data are presented.

Positive methods

Positive economic methods use observed data to make conclusions about the behaviour of economic agents. Based on these conclusions, the possibilities to affect this behaviour by various actions, usually government policies, are analysed. These methods in economics are, loosely speaking related to econometrics, and in general to the use of statistics in economic research. Econometric and statistical methods were among the first to be used by agricultural and resource economists in utilising spatially referenced data (Bokstael, 1996; Nelson and Geoghegan, 2002). This was partly dictated by the nature of the problems considered (land use changes), but also by the inclination of the profession in that time period towards these methods. The theoretical concept utilised in the land use research was based on the econometric models for discrete dependent variable. The simplest model is the one where the observed land use, intrinsically a discrete variable, is related to number of explanatory variables, both economic and physical. The choices of land uses are governed by an unobserved, latent variable, which is usually assumed to be the discounted net income from a given, spatially defined, parcel of land. The key assumption is that the owner of a land parcel considers all possible land uses for that parcel, compares the expected current and future discounted returns and chooses the one with the greatest value. This can be represented by:

(1) $$\begin{Bmatrix} LU_i = m \quad if \quad ER_i(m) > ER_i(k), \ \forall m,k, \ and \quad \mathrm{m} \neq k \\ \\ LU_i = k \quad otherwise \end{Bmatrix},$$

where *m* and *k* are land use (*LU*) indices for land parcel indexed as $i = 1,\ldots,N$. *ER* are the expected returns as a function of a given land use. Based on this rule, the probability of choosing any particular land use *m* is determined by:

(2) $$\Pr[\text{choice } m] = \Pr[ERm > ERk].$$

Since the expected returns on each land use are stochastic due to climate volatility, commodity price volatility etc., a number of explanatory variables can be used to determine these expected returns:

(3) $$ER_i = f(\mathbf{x}'\boldsymbol{\beta}_i, \varepsilon_i),$$

where **x** is a transposed vector of explanatory variables, $\boldsymbol{\beta}_i$ is a vector of coefficients and ε_i is a random error term. By substituting equation (3) in equation (2) and assuming logistic distribution of the error terms, the probability of a given land use choice *m* can be expressed through the standard multinomial logit regression:

(4) $$\Pr[\text{choice } m] = \frac{e^{\mathbf{x}'\boldsymbol{\beta}_m}}{\sum_{i=1}^{N} e^{\mathbf{x}'\boldsymbol{\beta}_i}},$$

where *e* denotes the exponent. Alternatively, if the distribution of the error terms is assumed to be normal (Gaussian), the resulting model is a multinomial probit. Once the estimation is completed and the coefficient estimates are obtained, one has to be careful with their interpretation. In this case the coefficients are not ellasticities, but are rather marginal effects that a change in the value of explanatory variable will have on the relative (to the base land use) probability of observing a change in land use.

These coefficient estimates are often used in performing policy analysis with respect to explanatory variables that can be influenced by government policies, such as prices of inputs and outputs (through subsidies, taxes, demand shifting etc.), regulations (zoning), conservation programs (through payments) etc. Based on the estimated coefficients, conclusions are drawn as to what changes in policies could bring about a desirable land use change (e.g. conversion from agriculture into forestry – reforestation) (Wood and Scole, 1998). This is then used to formulate policy recommendations. This econometric approach is not limited only to the research on land use changes, but could also be applied to the research related to adoption of various conservation practices, urbanisation, deforestation etc.

The econometric approach has been subject to some criticism (Nelson and Geoghegan, 2002). The criticisms are related to the assumptions of economic rationalism (the choices are made based on highest possible economic return), the ex-post nature of the analysis as well as the static nature of the analysis. Even after considering these criticisms, the econometric probability model approach in using spatially referenced data remains a powerful tool in explaining some observed phenomena. It is especially valid when the research relates to a single or relatively small number of land areas. For a regional, catchment or basin scale analysis more prescriptive, normative methods might be more appropriate.

Normative methods

Normative methods use a norm, a predetermined criterion (often determined by a value-judgment) and select from a set of possible choices, so as to meet that criterion. One of the theoretical concepts of normative economics is mathematical optimisation, where a function is optimised (minimised or maximised). Optimisation can be either constrained or non-constrained. Constraints can be used for more realistic depicting of the true situation, in comparison to the econometric method where the constraining behaviour is pre-determined in the choice set. Both the function to be optimised and the constraints can be linear, non-linear, dynamic or static. Since the model is normative, it can include social aspects in the analysis, such as externalities, total social welfare, etc.

In the case of land use research, the simplest linear programming model would suggest a choice of land use in each of the considered land parcels, so as to optimise the specified objective function, subject to certain constraints. For example, the function might be, in line with the assumptions of the econometric approach, the sum of the discounted economic returns from all land parcels in the considered region. This maximisation may be subjected to some physical (resource) constraints (water availability), environmental damage constraints (amount of nitrate leaching allowed) etc. The solution to the program will assign a land use to each of the considered parcels so that the objective is maximised and all specified constraints are met. An important implication of using spatially referenced data is that the land parcels are explicitly spatially defined, and the choice of land use in each parcel is a function of its spatially defined characteristics (soil, slope, etc.). Of course, this method can be used when the choice variable is other than land use (e.g. conservation tillage, BMPs, etc.) In general mathematical expression of the problem can be formulated as:

(5) $$\max_{i} \sum_{i=1}^{N} \pi_i = \sum_{i=1}^{N} ER_i(m, \mathbf{y}_i, \mathbf{x}_i)$$

subject to

$$\mathbf{y}_i \leq f_i(\mathbf{x}_i), \ \sum_i \mathbf{x}_i \leq \mathbf{X} \text{ and } g_i(\mathbf{x}_i) \leq Z_i,$$

where m denotes a land use in a given parcel (indexed by $i = 1,\dots N$); π_i denotes profit; ER_i denotes expected returns from a given land parcel; $\mathbf{y}_\mathbf{i}$ is the vector of physical or service outputs from the land parcel; $\mathbf{x}_\mathrm{i}$ is a vector of inputs (both controlled and uncontrolled). $f_i(\mathbf{x}_\mathrm{i})$ is a site-specific production function; $\mathbf{X}$ is the total endowment of resources (inputs); and $g_i(\mathbf{x}_\mathrm{i})$ is a function determining the environmental impact from using the inputs, a pollution generation function (Ancev et al. 2004). The total allowable amount of those environmental impacts may be constrained at some level of Z.

Alternatively, the objective may be to minimise the costs of meeting some requirements. Those requirements are typically related to environmental aspects, especially at the catchment level. For example, the newly formed catchment management authorities may want to establish the minimum level of water flow in their rivers and streams, or may want to set the maximum amount of nutrients leaving the agricultural land within the catchment.

There are considerable criticisms of the normative approach as well. One key criticism is that the objective function implies social context to essentially private decisions. Even though private agents would not in reality make decisions according to the predictions from the model, the derived results imply the actions that agents “should” take so as to maximise overall benefits. This can be used in formulating a policy that will attempt to bring about the desired changes.

While positive econometric models take the observed choices and explain them by GIS data, normative methods make use of GIS data to determine the optimal choices. While the former is more useful for the purpose of policy evaluation and adjustment, the later is more appropriate for policy formation. The former tells us *how* should something be done *where*, but the latter tells us *what* should be done *where*.

Biophysical simulations and their use in econometric and optimisation frameworks

Another important use of spatially referenced data in agricultural and resource economics research is through various biophysical models which are integrated with economic modelling. There is abundance of bio-physical models including plant growth models, field scale models (e.g. EPIC), hydrological models (e.g. SWAT, APEX), nutrient leaching models (e.g. VAWE), water quality models, etc. These models can be used in both econometric and optimisation frameworks for conducting economic analysis. For example, the SWAT model was used in an econometric setup by Tanaka and Wu, 2004 and in optimisation setup by Ancev et al. (2003) and Ancev et al. (2004). In Tanaka and Wu (2004) econometric models were estimated to predict changes in land use and farming practices under alternative policies in the upper Mississippi river basin. The predicted changes were then fed into the physical model, the Soil and Water Assessment Tool (SWAT), to predict their impact on NO_3-N concentrations in the Mississippi River.

This study started with econometric modeling, the results of which were used in a biophysical simulation to determine the effect of policy changes on the variables of interest. In contrast, Ancev et al. (2003) and Ancev et al. (2004), used SWAT as a primary model that generates the relationships of interest (phosphorus loading as a function of litter application in the former and deep-drainage as a function of alternative irrigation systems and water quantity in the latter case). In both cases the simulated relationships were incorporated as constraints in a mathematical program designed to maximize agricultural income on a catchment level. Constraints were parametrically varied to derive marginal costs (through shadow prices) of meeting various environmental targets.

The econometric approach to biophysical simulation first determines economic relationships and uses the biophysical models to simulate the effects of changes in those relationships. Optimization on the other hand takes physical relationships simulated through biophysical models and feeds them into an economic model which in turn determines the spatially explicit optimal configuration of choice variables (e.g. land use).

Methodological issues

In addition to the clear methodological differences between the positive and normative approaches of using spatially referenced data in agricultural and resource economics research, there are several methodological issues that are common to both approaches. One is the issue of a static (a single time period) versus dynamic (multiple time period analysis). Economics discipline has long been preoccupied with the dynamic modelling (Bockstael, 1996) and indeed, the argument goes, this focus has been one of the reasons for overlooking the spatial component until recently. However, the reverse is happening at the present, as the focus on the spatial perspective may distract economists from the temporal perspective.

The spatially referenced data usually comes as a cross-section (of land units – parcels) but most commonly there is access to time series data as well. Whether or not these "panel" data are always "balanced" (the time series are of equal length for all cross-sections) is an additional question. But, whether balanced or unbalanced spatially referenced panel data are used, the results from the economic analysis often refer to a single point in time. The problem is therefore in that the economic modelling is used to determine a single choice, implicitly assuming that it will be present for all future time periods. This substantially differs from observed reality where choices vary substantially over time. To overcome this shortcoming, the temporal dimension needs to be clearly acknowledged. A relatively simple way to do this is to explicitly state that the predictions based on the economic models are only valid for the time steps in imminent future. After each time step, the new situation should be observed, the spatially referenced data set should be updated with this new information and the models should be rerun using the updated data set in order to derive predictions for the following time step.

A second important methodological issue is the choice of the scale of modelling. When the decisions on the model are made, a question arrises whether it is better to model a single land unit (parcel) or to model at a catchment on even a basin level? The question then is whether to use an inductive (bottom up, start with small pieces and build the whole from the pieces) approach or deductive (start with the whole, and than derive conclusions about the pieces). The answer will of course depend on the circumstances, data available, expertise in simulation models (field or catchment scale) and other external factors. The advantage in single land unit modelling is the possibility to include more detail and be more precise in predictions. On the other hand, the advantage of using catchment scale is that the analysis can be conducted on more general issues of interest. The trend toward the catchment scale models has been accentuated by the recent policy movement toward managing resources on the catchment level (CMAs in NSW) as well as the holistic ecological approaches.

The final methodological issue noted here is the treatment of uncertainty in economic modelling. The uncertainty stems from both the spatially referenced physical data itself and from the data on economic variables. The remotely sensed data and even ground-truthing data are not perfectly accurate. These errors multiply as the data is used for biophysical simulation. The results from these simulations come in a form of point estimates, but the estimated variability is often available in the output of many simulation models. The treatment of this uncertainty has recently been reported in the literature (Cai and Rosegrant, 2004). One way to deal with this uncertainty is to formulate empirical density functions for the considered parameters (using Monte Carlo simulations) and to conduct sensitivity analysis of the results from the economic model as the values of the parameters are drawn from various segments of the distribution. Another source of uncertainty is the volatility in economic variables – prices, market conditions etc. While the econometric methods, more or less cover these uncertainties (by essentially assuming a distribution – logistic or Gaussian), optimisation methods do not typically account for it. If the uncertainties about these variables are of great concern then technique of stochastic programming (Birge and Louveaux, 1997) can be used as an adequate method.

Case studies

To provide examples of how spatially referenced data can be used in agricultural and resource economics research we offer brief summaries of three case studies in which the authors were involved or plan to be involved.

Phosphorus runoff on a catchment level

A study was conducted aiming at determining the cost-efficient means of reducing phosphorus loading in a catchment in Oklahoma in the US. The study determined the cost of environmental damages from phosphorus runoff through eutrophication (direct costs of drinking water treatment and cost of lost recreational values). The following spatially referenced data were used in the study: soil maps, land use (supervised classification), DEM, road network, etc. These data were used in an ArcView project that was integrated with the Soil Water Assessment Tool (SWAT) as biophysical model used to simulate phosphorus runoff from various land units. Since the phosphorus runoff was treated as a function of poultry litter applied on the agricultural land areas, simulations were run for various rates of litter application, various associated agricultural practices as well as land use changes within the catchment. Results from biophysical simulations were incorporated in a mathematical programming model that maximised agricultural income on a catchment level subject to parameterised phosphorus loading constraints. The results from the programming model were used to determine the optimal land use configuration, optimal litter utilization in the catchment and export of litter from the catchment, as well as optimal litter application rates to individual land areas. All of these results were spatially referenced to the specific spatially defined land units.

Deep drainage from irrigated cotton

This study was conducted with the aim to determine the cost of reducing deep drainage in catchments with significant land areas under cotton irrigation. Various irrigation practices were simulated within SWAT and the hydrological outcomes were recorded. A special consideration was given to irrigation water availability. The following spatially referenced data were used in the study: soil maps, land use (unsupervised classification), DEM, river and stream location data, stream flow data etc. The data were again used in an ArcView project integrated with SWAT. Deep drainage was simulated as a function of various amounts of irrigation water applied and under various irrigation systems in each of the considered land units planted with irrigated cotton. The outputs of SWAT simulations were used in mathematical programming model that maximised agricultural income on a catchment level subject to allowable deep drainage constraint and water availability constraint by source (surface and groundwater). The results from the program were used to derive marginal cost of reducing deep drainage on the catchment level. In addition, optimal irrigation system and quantity of irrigation water by source were determined for each spatially defined land unit.

Land use change in Hunter Valley, NSW

Currently the authors are working on a project proposal for modelling land use changes in the lower Hunter Valley, NSW. In contrast to the previously described applications, this will be a study using the positive, econometric approach. Time series land use data, soil data, road networks data will be used in conjunction with property price data, agricultural commodities price data, recreational visitations data, and other relevant economic data to build a probability model of land use changes. These data will be then used for estimation of an econometric model in either logit or probit frameworks. The resulting marginal effects will be used to determine the probabilities of land use change for the individual land areas. This will then be used to simulate future land use changes, which could be translated for policy recommendations and advice.

Conclusion

People live their lives in contexts and the nature of those contexts structures the way they live (Rindfuss and Stern, 1998). "Contexts" can be various things: political or administrative contexts (countries, states, political parties etc.), religious context, a social network, racial or ethnic context, educational, geographical and other contexts. Remote sensing and spatial referenced data provide an additional means of gathering contextual data, particularly in describing the biophysical context within which people live, work, grow crops, play and enjoy. These data can and should be used for economic research, in particular in the fields of agricultural, resource and environmental economics. Even though such use has been taking place in recent time, there are still plenty of unexploited opportunities to answer interesting questions through joint geo-scientific and economic research. This conjunctive research has been developing slowly in Australia, and it is the hope of the authors that this paper provides an impetus for consideration of these significant research opportunities.

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Table 1. Summary of literature contributions using spatially referenced data in agricultural, resource and environenmtal economics.

Author	Research area	Research sub-area	Enhancement through integrated approach
Bockstael 1996 Geoghegan et al. 1998	Land use change	General land use change	Land use changes explained by economic behaviour (present value of returns)
Swinton 2002		Agricultural (cropping patterns)	Optimal cropping
Nelson and Geoghegan, 2002 Wood and Skole, 1998		Forest (deforestation)	Determine the likely areas where deforestation could occur and the effects of policy change
Bell and Irwin 2002, Carrion-Flores and Irwin, 2004		Urban/rural (residential, industrial)	Determine the pattern of urban/rural sprawl
Antle et al. 2004		Carbon sequestration	Spatially referenced sequestration
Holloway et al., 2002		Adoption of new varieties	
Skop and Schou, 1999 Ancev et al. 2003 Yang et al. 2003 Tanaka and Wu, 2004 Maalaraachi and Quiggin.	Agricultural pollution	Nitrate leaching Phosphorus Runoff Land retirement Land retirement, crop choice, conservation Nitrate leaching	Combining soil formation with economic information to explain leaching levels Catchment level phosphorus runoff Catchment level Basin level Sugar cane in Australia
Bateman et al. 2002 Bastian et al. 2002	Environmental valuation studies	Hedonic pricing	Spatially referenced property price data
Bateman et al. 2002		Travel Cost	Better estimates for travel distance and time
Bateman et al. 2003		Benefit transfer	Better comparison of biophysical features between valuation and policy site
Khanna et al., 2003 Eigenraam, 2004	Policy Analysis	Preservation programs, CRP, etc. Land retirement	Site-specific policy formulation and analysis
Florax et al.2002 Ancev et al.2004	GPS	Precision agriculture	Better yield response functions estimates

Table 2

Examples of new and old sources of remotely sensed and spatial data for biophysical and economic modelling

Carrier	Sensor/Scanner	Land Cover Information	Data Sources (Australia or elsewhere)
Space-borne:			
Landsat	Thematic mapper, multispectral, panchromatic	vegetation, land cover, soil, etc.	ACRES (http://www.ga.gov.au/acres/)
Ikonos	Multi-spectral, panchromatic	crops, soil forestry, land cover	Space Imaging
Terra	ASTER (14 bands- VISIR to TIR),	crop inventory, soil forestry,	(http://www.spaceimaging.com/products/ikonos/)
Terra-MODIS, Aqua-MODIS	MODIS (36 VISIR bands)	soil, vegetation, moisture (drought	http://modis-land.gsfc.nasa.gov/
NOAA Satellites	(e.g., AVHRR)	soil, vegetation, moisture (drought)	http://edcdaac.usgs.gov/1KM/comp10d.asp
SPOT Satellites	High resolution visible (panchromatic and multispectral)	DEM, landscape, vegetation and moisture	http://www.spotimage.fr/html/
RADARSAT/ERS	Synthetic Aperture Radar (SAR)	DEM, crop vigour, soil moisture	http://www.rsi.ca/products/sensor/radarsat/radarsat1.asp
Shuttle Radar Topography Mission	SRTM SAR	DEM (most of global land masses)	http://seamless.usgs.gov/
Air-borne: (Aeroplanes and Balloons, HyMap)	Photogrammetric/videographic cameras SLAR VIS/NIR cameras (up to >100 bands in VISIR) Gamma-radiometer	DEM, crop growth, vegetation DEM, moisture, land use Moisture, clay, land use, etc. K, U and Th isotopes, soil types	NSW- http://www.lands.nsw.gov.au/MapsAndPhotos/didgitalpg.htm; http://www.minerals.nsw.gov.au/prodServices/mapsDigitalData/geophysData2;
	LIDAR	DEM and derivatives	Commercial agencies
Ground-based vehicles, humans (Proximal sensing)	Gamma-radiometer Yield monitors	K, Th and Ur counts, γ-ray Crop yield (ha^{-1}) and quality, land use patterns	Generally in-house developed data archives
Humans and existing information	Various, human	Existing ground-truth data and maps, etc.	http://www.lands.nsw.gov.au/MapsAndPhotos/didgitalpg.htm (NSW)