Bringing ecosystem services into economic analyses of land use

Presentation to:
Fondazione Eni Enrico Mattei (FEEM)
Isola di San Giorgio Maggiore, Venice, Italy
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Bringing ecosystem services into economic analyses of land use

Making better land use decisions: UK Case Study

Available from UNEP or Defra: [www.uknea.unep-wcmc.org](http://www.uknea.unep-wcmc.org)
or Bateman et al. (2013) *Science*, 341: 45-50
Making better land use decisions: UK Case Study

Drivers of land use change:

- Physical environment and its changes
- Changes in market forces, prices, costs, etc.
- Policy

Integrated analyses vital
Modelling agricultural land use: Data
Spatially referenced data for all of GB

**PHYSICAL ENVIRONMENT**
- Soils
- Temperature
- Rainfall

**MARKETS ETC.**
- Output prices
- Input costs
- Technology

**POLICY**
- Common Agricultural Policy
- Environmental Policy
- Intervention

2km square resolution; 55,000 cells; about 50 records per cell; data from 1972 to 2010
Agricultural land use model

Based on a joint (in inputs) multi-activity dual profit function (Chambers and Just, *AJAE*, 1989; Fezzi and Bateman, *AJAE*, 2011)

The farm objective function:

\[
\pi(p, w, L, z) = \max \{ \pi(p, w, z, l_1, \ldots, l_h) : \sum_{i=1}^{h} l_i = L \}
\]

Fixed factors: soils, temperature, precipitation, policy, etc.

Very flexible specification allowing for full interactions.

Using duality we can derive a series of relations, including estimates of the amount of land allocated to each activity. This varies spatially due to variation in physical environment and allows us to compare predicted with actual land use in an out-of-sample test.
Validation
Out-of-sample, actual versus predicted tests

Cereals

Actual
Predicted

Grasslands

Actual
Predicted
Drivers of land use: Climate change

Temperature

Rainfall

Drivers of land use: Climate change
Climate change impacts: Cereals 2014

L-Total - Baseline: Cereals
Climate change impacts: Beef 2014
Impact of climate change on tree growth

<table>
<thead>
<tr>
<th>m³/ha/yr</th>
<th>2010</th>
<th>2060</th>
</tr>
</thead>
</table>

**Sitka Spruce**
Likes cool wet conditions – so growth falls as climate changes

**Oak**
Responds positively to warmer weather
Greenhouse gases

Drivers

Impacts

Biodiversity

Food

Incomes

Land use

Timber

Market values

Non-market values

Social value

Recreation

Water

Drivers

Impacts

Greenhouse gases

Biodiversity

Food

Incomes

Land use

Timber

Market values

Non-market values

Social value

Recreation

Water
Land use change & water quality

Nitrate leaching per month

Linking land use with water quantity & quality
Land use change & water quality

Impacts of land use change on river water quality and ecosystems services
Linkage to the value of outdoor recreation

• Household survey data:
  o Home location
  o Location of visited sites
  o Visit frequency
  o Calculate visit travel time & costs

• Obtain data on water quality at sites

• Random utility model

\[ u_{ij} = \alpha_j + x_j \beta + \gamma (L_{it} - t_{cij}) + \epsilon_{ij} \quad (j = 0, 1, ..., J \text{ and } \forall i) \]

• Observed site choices reveal trade-off between site quality and visit costs:
  o As costs increase so visits fall
  o As quality increases so visits rise
  o Reveals value for improved sites
Compiling a comprehensive, GIS based dataset of recreational sites across Great Britain

Norfolk

Edinburgh
Extending the data set
Larger sample, all types of outdoor recreation

Monitor of Engagement with Natural Environment (MENE) survey

Final dataset contains 15 million respondent-site choice options

Outputs
- Recreation valuation model
- Recreation values for current and future land use
Recreation values: Status quo spatial distribution

Current recreational value (£K p.a.)

Population centres
Welfare gains from creating new recreational sites at different distances from population (e.g. woodland sites)
Land use change: GHG values ($\text{CO}_2$, $\text{N}_2\text{O}$, $\text{CH}_4$)

Carbon storage in crops & trees

Carbon release from harvest & felling

Soil carbon changes

Machinery & fertiliser emissions

Livestock emissions

Average annual GHG emissions 2014-63

Agriculture

Forestry

Soil type | Under grass | Under trees | Change
---|---|---|---
Peat | 120t | 45t | 75t
Rendzina | 200-400 | 200-400 | 0
Dusted | 200-400 | 200-400 | 0
Brown earth | n/a | n/a | n/a
Peat, eroded peatland | 130-410 | 120-410 | 10
Baggagley | 170-410 | 170-410 | 0
Land use impacts on Biodiversity

Data:  • Grid referenced
       • GB coverage
       • Time series

Breeding Birds Survey:
Bird diversity indices
Land use impacts on Biodiversity

Data:  • Grid referenced
       • GB coverage
       • Time series

Modelled linkages:

Climate change
↓
Land use
↓
Biodiversity
Land use impacts on Biodiversity

Lack of robust values means that biodiversity impacts were not monetised but rather are used as a constraint (see later)

Data: • Grid referenced
• GB coverage
• Time series

Modelled linkages:

Impact of climate change induced changes in land use 2014-63:
• Some increases in upland biodiversity
• Offset by losses in lowland areas due to greater extent and intensity of arable production.

<table>
<thead>
<tr>
<th>Measure of biodiversity change</th>
<th>Mean*</th>
<th>S.E. Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Birds</td>
<td>-0.248</td>
<td>0.006</td>
</tr>
<tr>
<td>Woodland Birds</td>
<td>-0.034</td>
<td>0.004</td>
</tr>
<tr>
<td>Farm Birds</td>
<td>-0.032</td>
<td>0.004</td>
</tr>
<tr>
<td>Red/Amber Birds</td>
<td>-0.092</td>
<td>0.002</td>
</tr>
</tbody>
</table>
Climate change and policy change
Policy scenarios

Further intensification, baseline environmental conservation

Increased environmental conservation with no increase in intensification

World Markets (WM)
Go With the Flow (GF)
Green & Pleasant Land (GPL)
Local Stewardship (LS)
National Security (NS)
Nature at Work (NW)
Why valuing ecosystem services matters

**Best option**

**World Markets Scenario**
Increased intensification of natural resource use to maximise market values

- **Market value gain**
  + £420 million per annum relative to the current baseline

**Nature at Work Scenario**
Sustainable use of natural resources to maximise net ecosystem service values

- **Market value loss**
  - £510 million per annum relative to the current baseline
Why valuing ecosystem services matters

Net value loss
- £18,990 million per annum relative to the current baseline

Net value gain
+ £17,920 million per annum relative to the current baseline
Net value loss
- £18,990 million per annum relative to the current baseline

Net value gain
+ £17,920 million per annum relative to the current baseline
Policy targeting

- Green & Pleasant Land (GPL)
- Go With the Flow (GF)
- Local Stewardship (LS)
- National Security (NS)
- Nature at Work (NW)
- World Markets (WM)
Policy targeting

Maximise market (farm) values

Maximise market & non-market values

Maximise market & non-market values with biodiversity constraints

Cumulative UK values (market & non-market)

Cumulative values

<table>
<thead>
<tr>
<th>Scenario</th>
<th>WM</th>
<th>GF</th>
<th>GPL</th>
<th>LS</th>
<th>NS</th>
<th>NW</th>
</tr>
</thead>
</table>

Change from baseline in the sum of market and non-market values (£/ha/yr)

<table>
<thead>
<tr>
<th>Loss &gt; 1000</th>
<th>Loss 500 to 1000</th>
<th>Loss &lt; 500</th>
<th>No Change</th>
<th>Gain &lt; 500</th>
<th>Gain 500 to 1000</th>
<th>Gain &gt; 1000</th>
</tr>
</thead>
</table>

£892m

£19,606m

£18,092m
Ongoing work: Optimal land use

Scenarios are typically determined by policy makers:
• No guarantee that the chosen scenarios include the best use of land
• Ideally we want to optimise across all feasible land use options

Requires economic models which incorporate:
• Economic and natural science data.
• Allows for spatial dependencies (e.g. substitution effects in recreation)
• Allows dynamic optimisation (e.g. selects the set of land use changes which maximise values over multiple years rather than just opting for the one which yields the highest immediate independent value).

• Case study under review (see authors for details)
Stylised optimisation problem

Suppose we want to create two new recreational sites

First-best optimisation

<table>
<thead>
<tr>
<th>Recreation sites</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utility</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>( \sum )</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Combinatorial optimisation

<table>
<thead>
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</tr>
</thead>
<tbody>
<tr>
<td>Utility</td>
<td>3</td>
<td>6</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>( \sum )</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Actual optimisation problem: Identifying the optimal 750,000ha out of the 20,933,100ha that make up Great Britain ensuring (for policy purposes) an equal division across the three countries of England, Scotland and Wales, planted evenly over a 50 year time horizon.

To solve this we used the IBM ILOG CPLEX solver
Future Research

• Uncertainty analysis (e.g. Monte-Carlo)
• Integrated analysis of threshold effects (e.g. biodiversity), resilience & shocks (e.g. extreme weather)
• Sustainable intensification and food security
• Offsetting (for biodiversity or wider natural capital): efficiency versus ‘equity’
• Development of decision tools
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